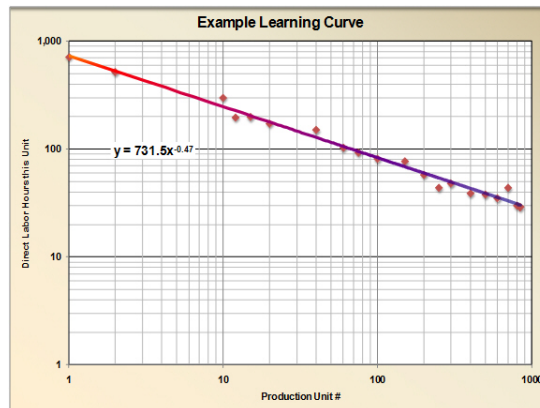


Learning & Experience Curves In Manufacturing

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Concepts & Continuous Improvement

Learning Curves have traditionally been used for cost estimating and training purposes. However, they have a much wider applications, including Manufacturing and Marketing strategy. They underly the concept of Continuous Improvement. Like compound interest, they generate large benefits from seemingly small, incremental change.

The learning curve came into prominence during World War II when Army Air Force scientists noticed that the cost for a given aircraft model declined with increased production in accordance with a fairly predictable formula. Each time the cumulative production doubled, cost declined by a fixed percentage. In the aircraft industry, at that time, this reduction was about 20%.

The mathematics is a bit complex and is unnecessary for purposes of Manufacturing Strategy. The important thing, for our purposes here, is to understand the general form of the typical curve, how various factors affect the curve and the resulting implications for Manufacturing and Marketing Strategy.

Basic Learning Curve Equation

$$Y = KX^{-N}$$

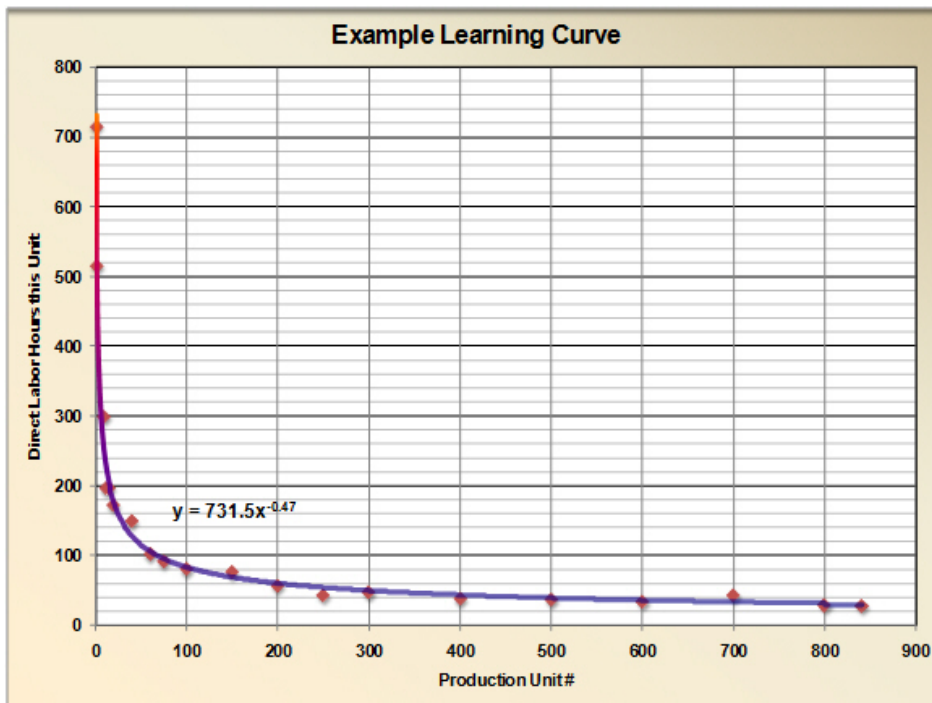
Y=Cumulative average cost of X units

K=Cost of unit #1

X=Number of units produced

N=Learning Exponent

This equation shows the total average cost for all units through the Nth unit. However, the cost of each Nth unit parallels the average cost after 20 or so units.



Unit #	Direct Labor Hours
1	716
2	516
10	300
12	197
15	198
20	173
40	150
60	103
75	93
100	81
150	77
200	58
250	44
300	48
400	39
500	38
600	35
700	44
800	30
840	29

Figure 1 This linear scale shows direct labor per piece as a function of total pieces produced.

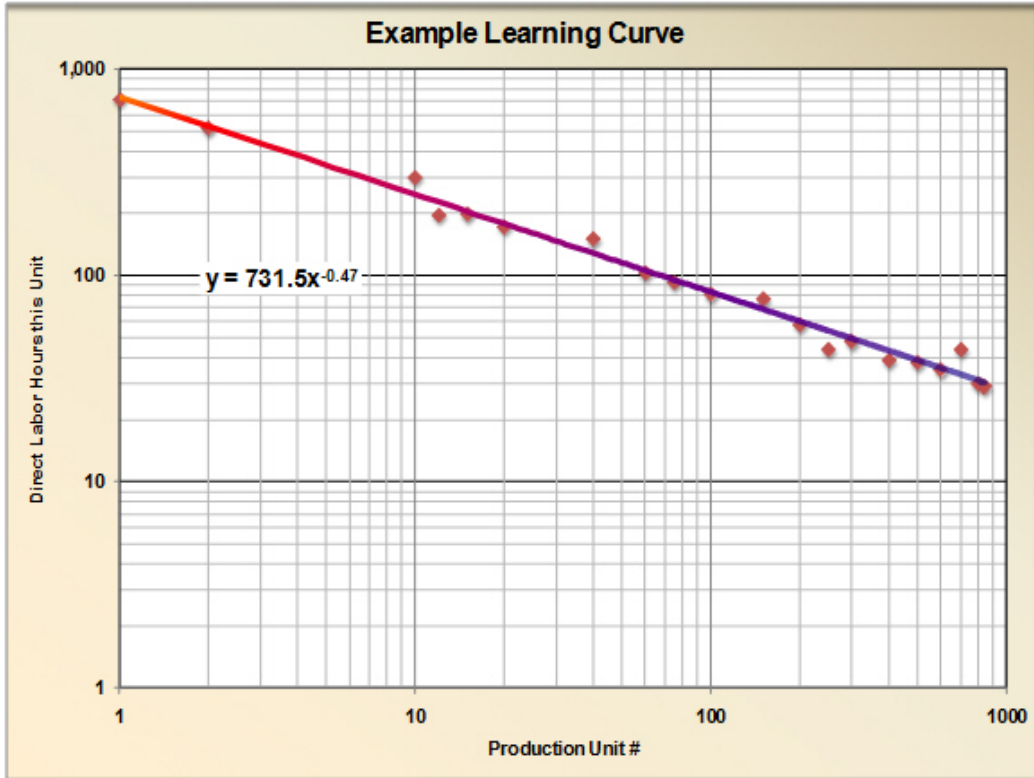


Figure 2 log-log scale makes the data appear as a straight line. The slope of this line reflects the amount of "learning" that takes place.

Table 1 Typical Learning Rates

Key Features

The example of figures 1 & 2 is typical of many situations. Direct labor hours for each unit of production drops rapidly during production startup. The improvement from one unit to the next becomes smaller and smaller but it does continue, often for decades. When plotted on a log-log scale, the data approximates a straight line as in figure 2. The slope of this line indicates the intensity of "learning" or improvement. Hence the phrase "steep learning curve" indicates a situation where improvement is coming quickly.

Representative Learning Rates	
Aerospace	15%
Shipbuilding	15%-20%
Machine Tools (New Models)	15%-25%
Electronics (Repetitive)	5%-10%
Electrical Wiring (Repetitive)	15%-25%
Machining	5%-10%
Manual Assembly+25% Machining	20%
Manual Assembly+50% Machining	15%
Manual Assembly+75% Machining	10%
Punch Press	5%-10%
Raw Materials	5%-7%
Purchased Parts	12%-15%
Welding (Repetitive)	10%

The concept and general form of the function applies to a wide range of industries. It also applies on a wide range of scales from the individual worker performing a specific task to national economies such as China. It works for:

- Individuals
- Workcells & Work Teams
- Factories
- Firms
- Industries
- National Economies

Most examples in the literature illustrate learning curve effects on direct labor. However, many other dimensions of manufacturing performance follow the same pattern. Examples are quality, delivery and (over the long term) total cost.

Table 1 shows representative learning rates compiled from various sources in the literature. The percentages are the improvement that comes with each doubling of cumulative production. There will be considerable variation from one organization to another within these large categories.

Learning Is Not Pre-Ordained

Performance gains from the learning curve effect are common but not universal. There is no physical law that requires individuals, work groups, companies or industries to learn from their experience. Performance gains come from a variety of mechanisms discussed below but behind these mechanisms is a willingness to learn, an ability to learn and, in many cases, an investment in learning.

Individuals, work groups, companies and industries that do not have the willingness, ability or investment may find their costs declining very little or, even increasing. The most common cause of slow learning is the willingness component that results from corporate or industry arrogance. The Detroit automakers in the 1960's and 1970's possessed a great deal of arrogance that prevented them from learning from the Japanese or even their own experience. It was not until declining market share and bankruptcies forced a bit of humility that these companies began their comeback.

What Determines The Slope

Many factors can determine the learning curve slope for a given individual, team, factory or industry. Among these are:

- **Management Styles & Actions**
- **Corporate Culture**
- **Organization Structure**
- **Technology**
- **Capital Investment**
- **Engineering**

Sources of Cost Improvement

Product Design—As products mature they often go through redesigns. One purpose of this redesign should be making the design easier and less expensive to manufacture. Designers can become more familiar with Design for Manufacturability. Improved coordination and communication between manufacturing and the designers also helps.

Direct Labor Efficiency—improvements in the arrangement of the workplace, improved balancing of work, motivation and improved equipment are among the contributors to direct labor learning.

Indirect Labor Efficiency— material handling, coordination, scheduling, maintenance and other support activities often consume more labor than actual production. Improvements here are just as important as direct labor but are often harder to quantify.

Economies of Scale—large scale equipment may lower costs in several ways. For example one machine with twice the capacity may cost less than two machines with only half the capacity. A small paper machine may require the same size crew as a larger machine but produce far less paper. Sometimes, however, there are dis-economies of scale. Larger factories, for example, often are less efficient than smaller focused factories.

Plant Layout—An effective plant layout simplifies workflow reduces handling cost and improves coordination. It often reduces inventory as well. Such a layout often implements Cellular Manufacturing and is a first step in Lean Manufacturing initiatives.

Process Improvement—takes many forms at many levels. The small but numerous improvements that result from 5S can be as effective, cumulatively, as a piece of major new equipment. Process improvements can also be simply a change in sequence of operations or the elimination of unnecessary steps.

Learning Curves In Cellular Manufacturing

Workcells are nearly an ideal environment for fast learning. They tend to be focused, team environments where lessons learned propagate quickly.

Workcell Performance

Figures 3 & 4 show the actual performance of a workcell that produced mechanical control cables. This is fairly typical of well-designed and properly implemented workcells. After about three weeks the cell had doubled productivity. At the workcell level (e.g. small work groups with limited product mix), improved productivity is from several sources.

Maintain the Learning

The slope of the learning curve is not fixed. It can change for the better through management action and training. Or, it can change for the worse, mostly through neglect. It is easy and exciting to participate in the learning experience when first starting because the improvements are dramatic and quick. As production continues for years or decades, improvements are slower in coming and incremental in nature.

In the long run, the effective maintenance of learning, continuous Improvement, may be more important. It can give a company a competitive advantage that is not easily duplicated by competitors. Toyota, again, is the prime example.

Figures 3 &4 show the actual labor productivity for a new workcell making mechanical control cables.

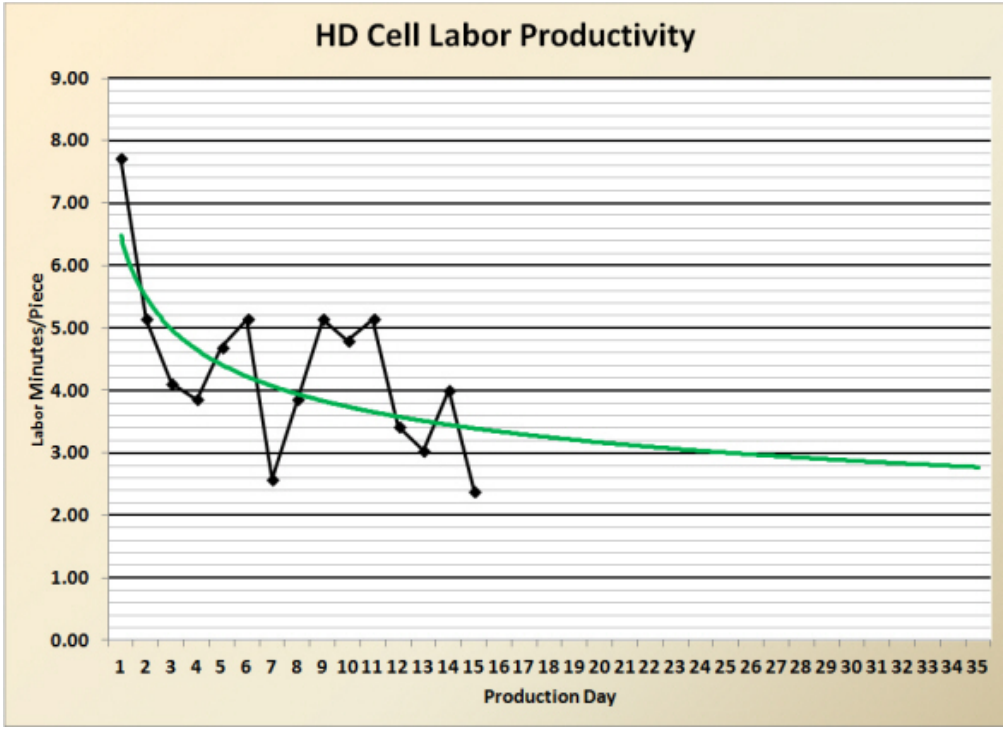


Figure 3 Actual Labor Productivity (Linear)

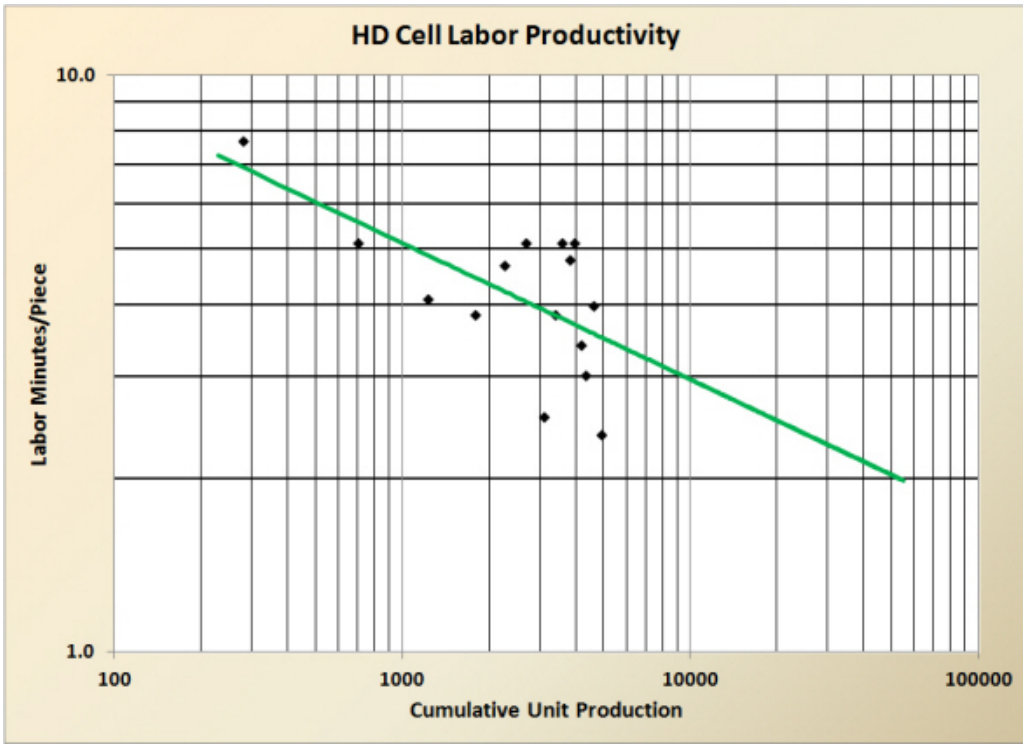


Figure 4 Actual Labor Productivity (Log-Log)

Sources of Improvement in Workcells

From a Socio-Technical perspective, these sources are either technical improvements from equipment and processes or social improvements involving the skills and interactions of people. Both are important and mutually reinforce.

Technical Improvement

Technical problems with equipment, maintenance and tooling have a way of standing out in a cellular environment. Partly, this is because they tend to shut down or slow down the entire cell.

In the HD cell illustrated before, the high labor hour days usually came from equipment breakdowns or tooling problems that required repair time. In each case, attention was given to ensure proper repair or modifications that would solve the problem permanently. As these changes accumulated, productivity improved. Moreover, the cell became more predictable with less day-to-day variation in output.

The internal lot size or transfer batch was reduced. And, the work team rearranged equipment to bring it closer together, this reduced space, reduced walking effort and improved communication.

Social Side Improvements

Social side improvements come from motivation, task skills, team skills, and problem-solving skills. Several of the best methods for balancing work within the cell depend upon mutual cooperation as well. A workcell team may have a wide degree of autonomy. Some teams operate almost entirely by themselves with only occasional coaching and supervision. Others may have a supervisor or working team leader.

Motivation—in a team setting, motivation is enhance for most people. Individuals do not want to disappoint the team. This relates to Maslow's Heirarchy of Needs.

Team Skills—these "team process" skills are not innate and, for most of us, must be learned through training and practice. This requires time and may vary among different groupings of people. One or two days of team training followed by continued coaching is usually the best way to impart these skills. A team leader or coach may promote these skills without formal training of the team but this is highly dependent on the individual.

Work Balance—a series of tasks is never balanced perfectly. Even highly engineered, automotive-style assembly lines lose 20% or more to imbalance. There are several ways to achieve better balance in workcells. But, they require motivated employees and time to develop skill. As the team matures, they get better and better at balancing.

Task Skills—part of the productivity improvement from workcells comes from improving and expanding task skills. If a particular worker is less skilled, that lower skill quickly becomes a bottleneck that limits team performance. In most cases, the team will correct the problem by teaching their less-skilled member. It is also important for each worker to expand their task skills with cross-training. this makes it easier to balance the work and get maximum performance from the team.

Problem Solving—training for workcell teams often involves the traditional problem-solving or process improvement skills from Work Simplification, TQM and Six Sigma. This can accelerate improvement and teamwork as it helps the team achieve success.

Quality—order of magnitude improvements in quality are not unusual. This is especially the case for cells that involve a lot of manual work and where quality depends on focus, attention and motivation. Teamwork, engagement, proximity and rapid feedback seem to be the important factors. See our page "The Psychology of SPC" for more.

Experience Curves In Manufacturing

Experience Curves are an expansion of the Learning Curve idea from individual and group learning to factories, companies or entire industry sectors. Companies can use Experience Curves to develop marketing and manufacturing strategy. Experience Curves are usually established over longer time periods than Learning Curves. In addition, market price is often used as a substitute for actual cost since costs for such a wide-ranging study are often unavailable.

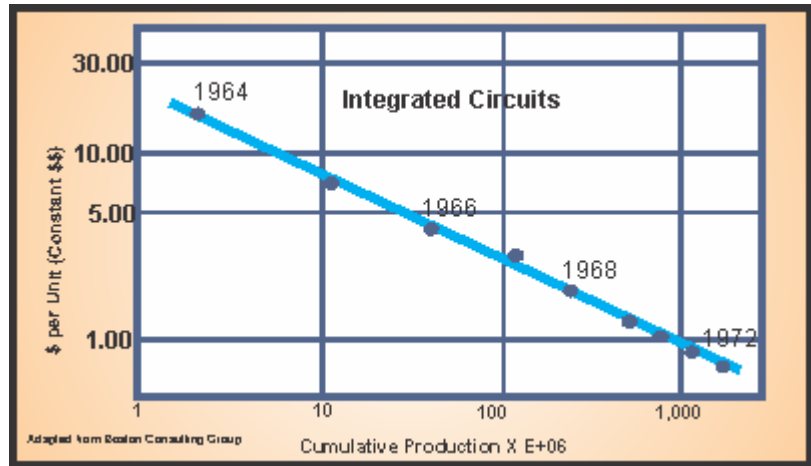


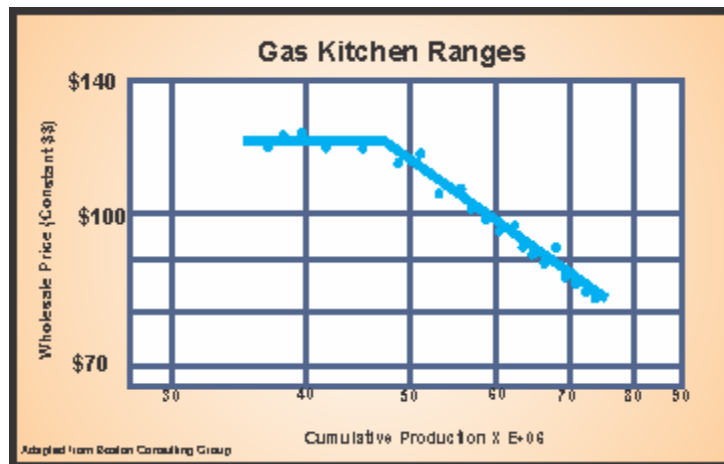
Figure 5 Experience Curve Integrated Circuits

Experience curves are similar in behavior and are often represented by the same formula as Learning Curves. There are however, some differences.

Experience curves relate to entire factories, companies or industries rather than individuals or work teams. They cover longer periods—years or decades rather than a few weeks or months.

The cost improvements are often the result of macro-level changes in systems, technologies and culture rather than individual or group experience.

Improvements from individuals and work groups certainly can contribute when widespread and accumulated over time.



These differences between Learning and Experience curves result in differences in their use and application. Experience curves apply to Manufacturing, Marketing and Business strategy. This contrasts with Learning Curves which are most useful for tactical applications such as evaluating work group performance or estimating product cost.

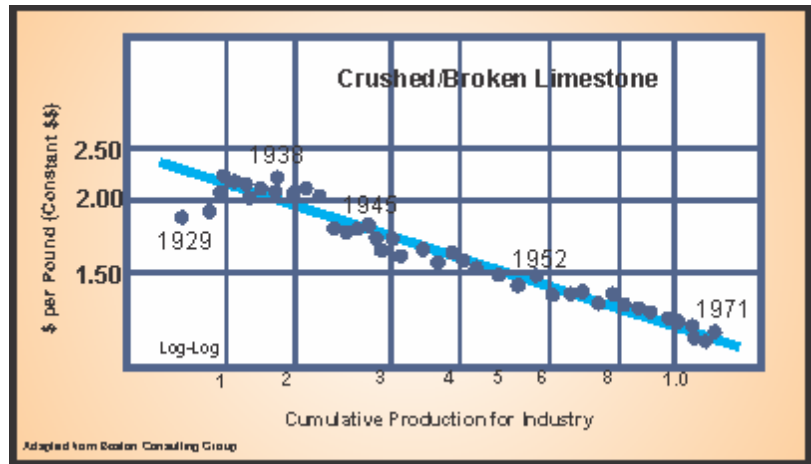


Figure 6 Crushed/Broken Limestone

The concept was first proposed by Bruce HENDERSON of the Boston Consulting Group (BCG). Figures 5-8 at right show some results of BCG's research. Here are some key points:

- The steady decline with each doubling of cumulative volume is remarkably consistent and continues over very long timeframes. The phenomenon appears in a wide range of industries and products.
- While early studies implied that there was no end to the cost declines, various factors surely place limits on the decline. If a thing cannot go on forever, it won't.
- The dog-leg shape for Kitchen Ranges and PVC Resin is apparently caused by the substitution of market price for actual cost. It is likely that the large companies in these industries maintained their pricing even while their costs were decreasing in order to derive higher profits.

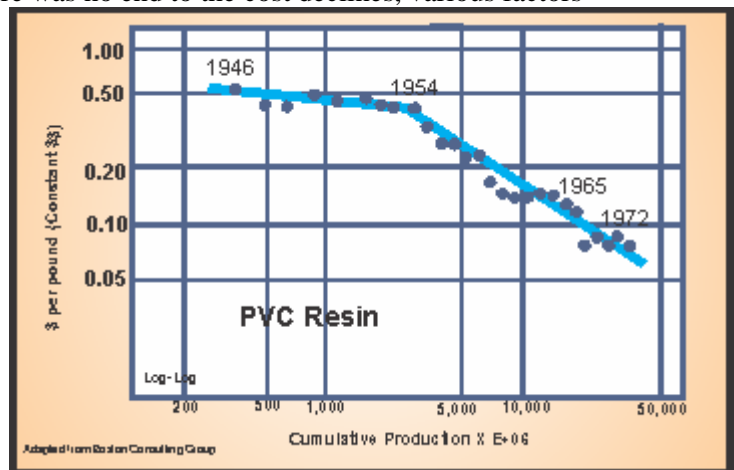


Figure 7 PVC Resin

Experience Curve Characteristics

Typical Experience Curve Slopes

The slopes of Experience Curves tend to range from 60% to 90% with an average of about 85%. This is the conclusion of GHEMAWAT from a compilation of 97 academic studies. It is also the range generally seen in the literature. Learning slopes also vary by industry and process type. The distribution of Ghemawat's study is in figure 5.

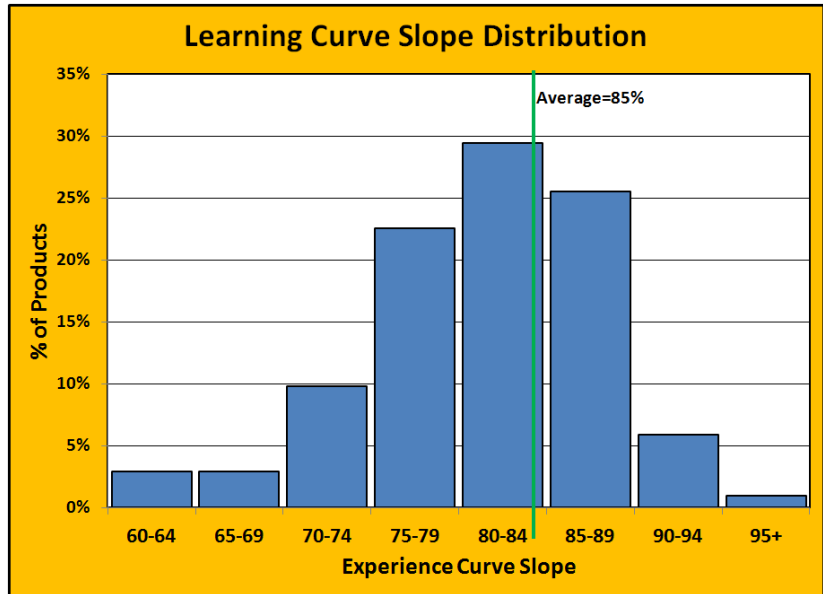


Figure 8 Distribution of Learning Curve Slopes

Competitive Effects of Improved Learning

Two firms, "A" and "B", have constant sales and constant market share but different learning rates. Figure 6 shows their cost performance over time. Note that the horizontal scale is in time units (quarters), not cumulative production.

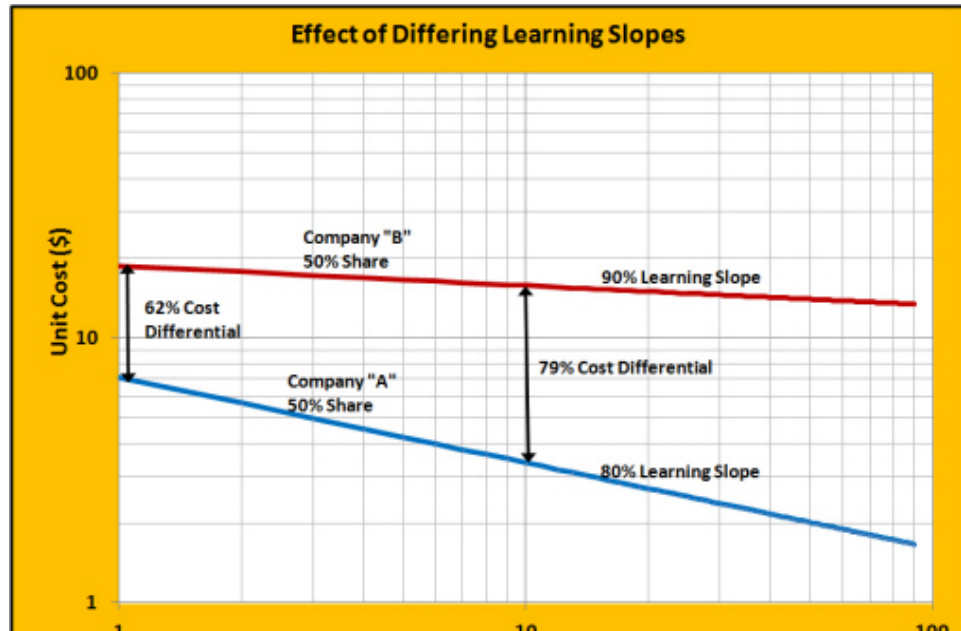


Figure 9 Effect of Differing Slopes

Company "A" has a steeper slope where costs at each doubling are 80% of the previous costs. In nine fiscal quarter, Company A's cost advantage has gone from 62% to 79% over Company "B". This is true even though both companies have the same market share and the same production volume.

Company A's management has developed a culture of improvement and/or investment policies superior to Company B.

Market Share Effects

Much has been made about the effects of market share and the idea of building a long-term strategy on increased market share, increased learning and lower pricing. Our exploration of several models suggest that the slope of the learning curve is far more important than market share.

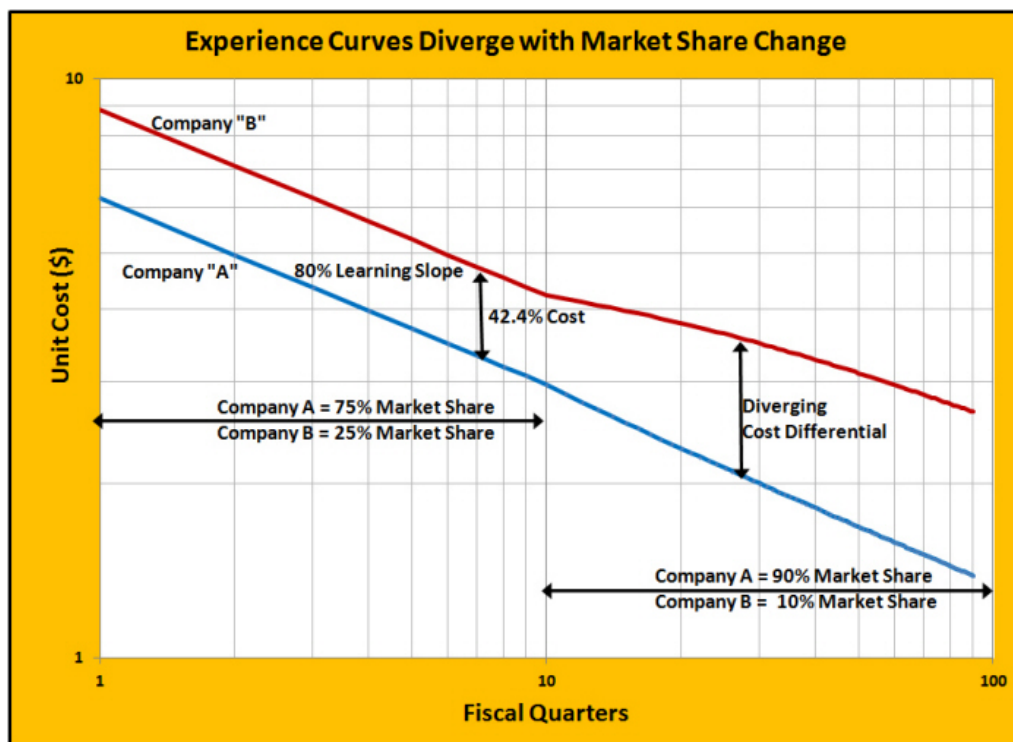


Figure 10 Market Share Effects

Figure 7 illustrates. Here, two firms, "A" and "B" have the same learning slope but firm A has three times the production and market share as firm B. With no change in market share for the next 10 quarters, the relative cost advantage remains constant even though cost for both firms is declining. After the tenth quarter, firm A increases market share, presumably by using its cost advantage to lower prices. At this point, the cost advantage of firm A widens but quickly stabilizes at a new point. Our model suggests that a difference in learning slope would have much greater effect than market share changes over any reasonable time-span. This will be important when we consider marketing strategies.

Learning & Experience Curves In Manufacturing Strategy

Focused Factories

When Wickham SKINNER wrote his seminal article on The Focused Factory, he was observing one effect of the Experience Curve. Any work unit, whether factory, workcell or company, will learn attain a higher learning rate when their range of products, processes and problems is narrower.

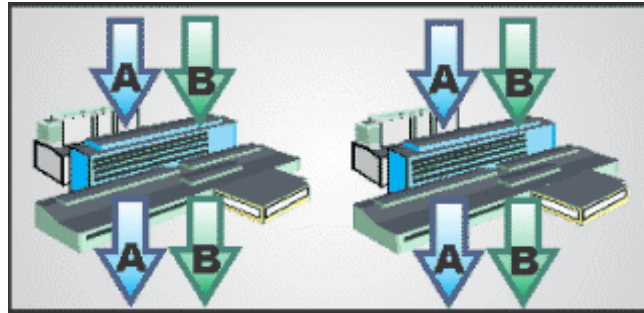


Figure 11 Unfocused Factories

In figure 1, two identical factories each build two separate products. In figure 2, each factory focuses on only one of the two products. The complexity is cut in half and volume doubles. This increases the velocity in learning and reduced complexity enhances the learning rate.

Other factors such as freight costs or delivery time may outweigh the advantages of learning, focus and reduced complexity. Such situations should be analyzed carefully and defined in a firm's Manufacturing Strategy Statement.

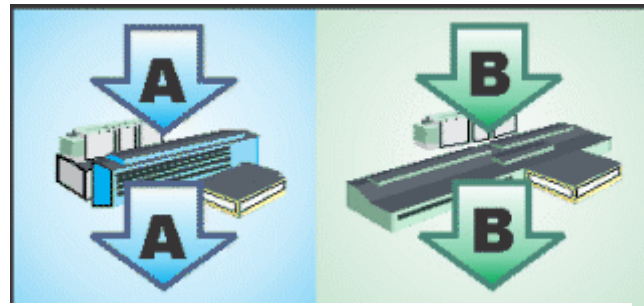


Figure 12 Focused Factories

The principle of focused factories can be extended to smaller-scale work units within the factory. To the extent that sales volume justifies it, production within a factory should be focused on particular products or product families. This usually takes the form of workcells and dedicated flow lines with a few functional areas (such as painting).

Implications for Marketing Strategy

There are many links between Marketing and Manufacturing Strategies. Ideally, these should be consistent and well-thought-out. In this article we only address those links and issues that directly relate to Learning and Experience curves and with respect to a few generic marketing strategies.

Some marketing strategies rely on unique product design, advertising or product positioning to attract customers. Such strategies do not depend, in a primary way, on Manufacturing. Manufacturing must meet reasonable expectations for cost and delivery but does not require outstanding performance. Learning Curves still affect profitability and this will always be a concern for managers and stockholders. But lowest cost is not a prerequisite for the marketing strategy or company survival.

Price Leadership/Cost Minimization Strategies`

With this strategy a firm attempts to dominate their market by offering products at or near the lowest price. This implies that the firm's cost is at or near the lowest cost in the industry. Hence, learning curve effects play a key role.

The Role of Market Share

Market share effects related to Learning and Experience Curves were discussed earlier. Figure 14 shows how these elements and consequences form a circular cycle that can lead to increasing market dominance. When the market share, relative to competitors, increases it brings increasing volume. The increased volume brings more learning and more cost reduction. If cost reductions are translated into lower prices, the lower prices bring even more volume and, eventually, market domination.

A firm that already leads its industry in market share must have a learning rate that brings cost reductions at least as fast as the reductions for competitors. If other firms have larger market share, the learning rate must be faster than those competitors in order to offset their cost and learning advantage. Without such learning rates, the strategy will eventually fail.

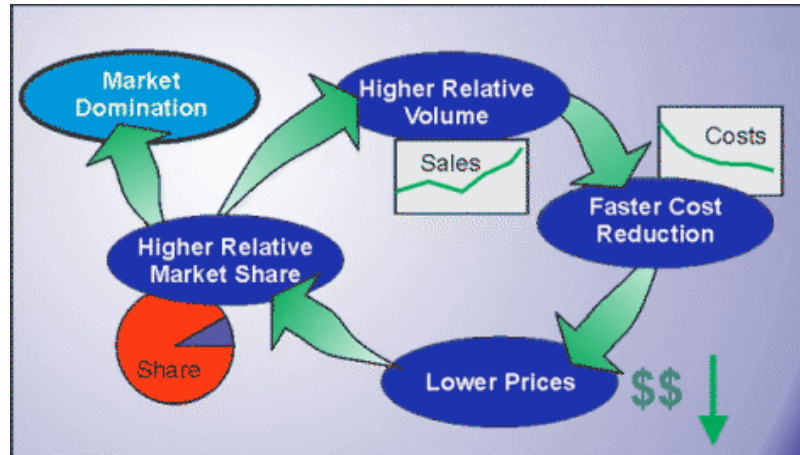


Figure 13 Market Share & Price Leadership

Making It Work--Other Aspects

A high learning rate is not enough, by itself, for successful Price Leadership. A successful Price Leadership strategy will probably require at least the following additional elements:

Leading Capacity Strategy

This refers to a capacity policy that puts capacity in place before market demand actually exists. To harvest the market share available from low prices, the product must be available when customers ask for it. Since capacity requires a finite time to put in place, a firm cannot simply wait until demand is certain.

High/Risky Capital Investment

The firm that employs a Price Leadership strategy must, usually, have the financial resources for and be prepared to make significant and, often risky, investments. Partly, this is the result of the necessity for a Leading Capacity Strategy. It is also because learning effects and cost reduction will partly depend on having the best available process technologies.

Aggressive Pricing

When cost goes down, management can use the savings to reduce prices. Or, management may use the savings to increase profit and provide immediate benefit to shareholders. Maintaining a Cost Leadership marketing strategy usually requires aggressive pricing to ensure the continuation of the circular cycle of figure 14.

Niche Strategies

Niche strategies allow smaller firms to compete in markets that may be dominated by much larger firms with lower costs, greater resources and lower pricing. A niche strategy identifies smaller

market segments that are often ignored by larger firms. It then develops a marketing mix that addresses unique needs and characteristics of that target market.

The needs of the target markets may or may not place unique demands upon manufacturing. These needs should be carefully analyzed and the means for meeting those special needs incorporated in the firm's Manufacturing Strategy. While low cost and other learning effects may not be critical to strategic success, it certainly helps profitability.

Innovation Strategies

Apple is the model for innovation strategies. The idea is to create innovative product designs that command a premium price. This can allow a relatively small firm to compete in the market and, possibly, create whole new markets.

A key element is having the capacity to meet initial customer demand when the new products are released. Without this capacity, sales will suffer, market share will not meet its potential and competitors have time to react. Therefore, a leading capacity strategy is essential and this strategy can be quite risky because the size of the market and potential demand is unknown. Highly innovative products may need equally innovative process technologies for the manufacture. This must also be in place prior to new product launch and increases risk even further.

Learning Curve effects play a somewhat different role with innovation strategies. Of course, it is important to learn how to produce the product quickly and with high quality. In addition, there is a sort of second-order learning that should occur. The firm must learn how to develop, launch and manufacture new products quickly.

Fashion Strategies

Fashion strategies depend upon product design more than manufacturing capability. As the name implies, they involve the design of new variations for what is, essentially, a conventional product with conventional processes. The latest dress design may appear different than last year's model but the manufacturing process is the same.

Learning & Experience Curve Synopsis

- For each doubling of total accumulated volume or repetition, cost, labor and other inputs decline by a fixed percentage, often in the range of 5%-25%.
- Many factors, including management attention, determine the specific "learning rate".
- The concept applies across a wide range of activities and organizations from individuals to entire industries.
- The reductions are consistent over long time periods of years or decades.
- At the level of workcells and workstations future cost declines are predictable.
- At the level of Companies and industries there are important implications for Marketing and Manufacturing Strategy.

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