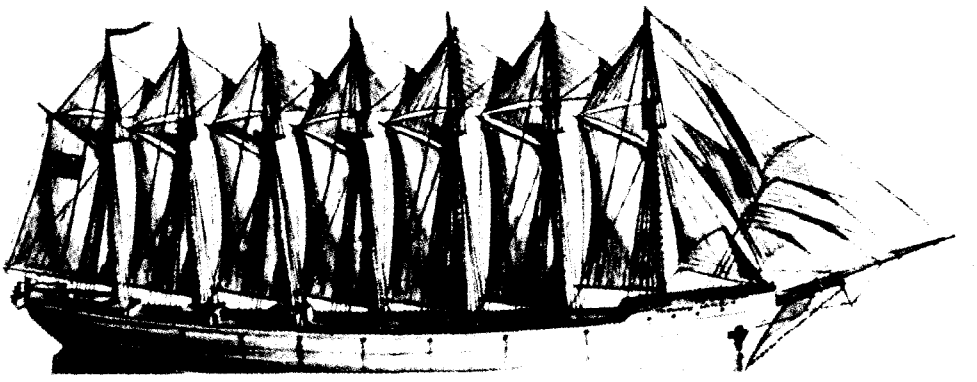
Toward dawn on Friday, December 13, 1907, the sailing ship ***Thomas*** W. ***Lawson*** sank off the Scilly Isles in the English Channel. Ail but the captain and one crew member were lost. This would have been just another Friday the thirteenth shipwreck, but the ***Thomas Lawson*** was special. It was a beautiful, huge ship with seven masts (Exhibit 1). It had been designed to compete against the new steam-powered vessels that had increasingly taken cargo business away from sailing ships. Constructed by the Fall River Ship and Engine Building Company, the ***Thomas Lawson*** could travel at 22 knots if the winds were brisk. But to gain swiftness her designer had had to sacrifice maneuverability. She was unwieldy and difficult to handle. In fact, she was so unstable she capsized while at anchor during a severe gale. According to one account, she was found in the morning looking "not unlike the back of a whale . . . the vast hull on its side washed by the seas." No attempt was ever made to design a faster cargo-carrying sailing ship. The builders and their employees sought other things to do. The age of commercial sail ended with the ***Thomas*** Lawson, and steamships began to rule the seas.

In May 1971, National Cash Register of Dayton, Ohio, stunned its workers, managers and investors by announcing



1 The *Thomas W.* Lawson, 1902 to 1907.
The Lawson's seven masts crowded as much sail above her decks as the limits of space and windflow would allow.
Source: Angelucci, Enzo, and Cucari, Attilio, *Ships*, New York: McGraw-Hill, 1975.

that $140 million worth of newly designed cash registers were impossible to sell and would be written off. In the months that followed, thousands of workers were laid off and the CEO was fired. The stock price fell from 4.5 to 14 over the next four years. The problem? The machines used electromechanical parts and could not compete with new, cheaper to make, and easier to use electronic machines.

In 1947, Procter & Gamble introduced Tide, the first synthetic laundry detergent. It was superior to the conventional natural detergents because it contained phosphate "builders" which improved its cleaning power. At that time P&G's major competitor in detergents was Lever Brothers. But Tide changed all that. Its sales took off, leaving Lever far behind, unable to match P&G's technical achievements. Lever eventually responded with its own synthetic product

called Surf, but it was too little too late. P&G had stolen the lead.

In each of these cases and many more like them, companies that were leaders in their field saw their fortunes suddenly disappear. Do leading companies in fact not have the natural advantages they are supposed to or are their natural advantages outweighed by other inherent disadvantages? I think the latter is the case, and that these disadvantages result from technological change. Technological change is the reason why only one company out of three manages to cover its cost of raising money most of the time. Why most companies manage to achieve what Bob Waterman and Tom Peters have defined as excellent financial performance in only one year out of twenty, and then immediately drop back into the great middle ground of average financial performance. Why even the best companies, by anyone's definition of excellence, retain their superior competitive performance for only three to four years. Why only one manufacturing company in the United States during the last twenty years, Xerox, has been able to sustain a position of financial leadership* in its industry for ten years.

UNDERSTANDING THE DYNAMICS OF *COMPETITION*

The roots of this failure lie in the assumptions behind the key decisions that all companies have to make. Most of the managers of companies that enjoy transitory success assume that tomorrow will be more or less like today. That significant

* Financial leadership means being ranked in the top third of industry in return on equity and sales growth for at least half of the 18-year period from 1965 to 1983.

change is unlikely, is unpredictable, and in any case will come slowly. They have thus focused their efforts on making their operations ever more cost effective. While valuing innovation and espousing the latest theories on entrepreneurship, they still believe it is a highly personalized process that cannot be managed or planned to any significant extent. They believe that innovation is risky, more risky than defending their present business.

But companies like IBM, Hewlett-Packard, Procter & Gamble, Johnson & Johnson, United Technologies, Harris, and Corning have all made the opposite assumptions. Their managers have assumed that the day after tomorrow will not be like today. They have assumed that when change comes it will come swiftly. They believe that there are certain patterns of change which are predictable and subject to analysis. They have focused more on being in the right technologies at the right time, being able to protect their positions, and having the best people rather than on becoming ever more efficient in their current lines of business. They believe that innovation is inevitable and manageable. They believe that managing innovation is the key to sustaining high levels of performance for their shareholders. They assume that the innovators, the attackers, will ultimately have the advantage, and they seek to be among those attackers, while not relinquishing the benefits of the present business which they actively defend. They know they will face problems and go through hard times, but they are prepared to weather them. They assume that as risky as innovation is, not innovating is even riskier.

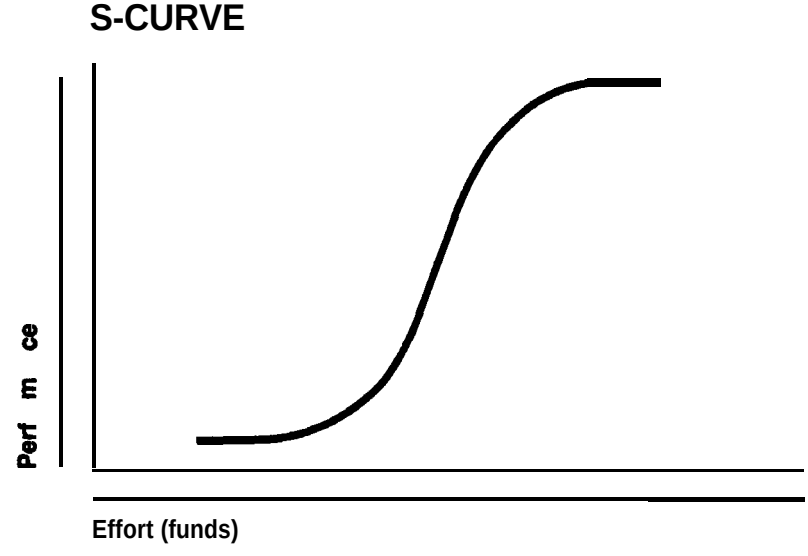
The beliefs of successful companies are not accidental; they are based on an understanding of the dynamics of competition. To understand these dynamics, which manifest themselves every day in the business press, we need to under-

stand three ideas: the S-curve, the attacker's advantage, and discontinuities.

THE S-CURVE

The S-curve is a graph of the relationship between the effort put into improving a product or process and the results one gets back for that investment. It's called the S-curve because when the results are plotted, what usually appears is a sinuous line shaped like an S, but pulled to the right at the top and pulled to the left at the bottom (Exhibit 2).

Initially, as funds are put into developing a new product or process, progress is very slow. Then all hell breaks loose as the key knowledge necessary to make advances is put in place. Finally, as more dollars are put into the development



2 **The S-Curve.**
The infancy, explosion, then gradual maturation of technological progress.

of a product or process, it becomes more and more difficult and expensive to make technical progress. Ships don't sail much faster, cash registers don't work much better, and clothes don't get much cleaner. And that is because of limits at the top of the S-curve.

LIMITS: A NEW WAY TO THINK ABOUT TECHNOLOGY

Limits are fundamental to both our personal and our business lives. In everything we do or make we are governed by limits. We cannot go beyond them, so when we approach them we must change or not progress anymore. We all implicitly understand that. In July 1985, Sergei Bubka of the Soviet Union broke the world pole vault record, clearing 6 meters (19 feet 8¼ inches) during the Paris International Track and Field meet. Asked if he ever expected to reach 7 meters (22 feet 11¾ inches), he replied, "No, there will have to be another ***technical revolution*** before that height can be reached." There's just so high you can jump using a bending fiberglass pole.

In the world of business, limits determine which technologies, which machines and which processes are about to become obsolete. They are the reason why products eventually stop making money for companies. Management's ability to recognize limits is crucial to determining whether they succeed or fail, because limits are the best clue they have for recognizing when they will need to develop a new technology-

By technology I mean several things. In some cases it's a specific process-say a chemical process-that produces a specific product. In this case it's hard to distinguish the **prod-**

uct from the technology. More broadly, technology can mean a manufacturing process, say continuous casting of steel **versus** the open-hearth method. Here the technology is distinct from the product. The cash management account (CMA) is another example of a distinct process and product. New information processing technology made the CMA possible. We can think of technology even more broadly as the general way a company does business or attempts a task-the production line versus batch processing or the sidelong high jump technique versus the backward-first Fosbury flop.

The point is this: technology even variously defined always has a limit-either the limit of a particular technology, for example, the ultimate density of devices we can get onto a silicon chip, or a succession of limits of several technologies that together make up the larger technology or product or way of doing business.

It's easy to see how these limits will affect performance and sales of a product when the technology and product are closely associated. It's not so easy to see the importance of limits when you are dealing with something like air travel, which results from thousands of technologies. But usually there are one, two or several technologies that are crucial to a product or its production (the semiconductor chip in a computer or the pole in the vaulter's hands), and these are the technologies with which managers, inventors and all of us ought to be concerned.

All of us know about limits, but often companies do not recognize or act on them. This lesson was brought home to me a couple of years ago when I was visiting a paper mill in Alabama. This particular company had erected a new mill alongside an old one. Our tour began in the old plant. As we strolled through the control room I could see engineers

watching their production statistics being automatically tabulated on paper charts and computer forms. I asked about the possibility of electronics replacing paper, say by having TV monitors replace computer forms in office applications. My host graciously but firmly told me this would never happen. Paper was too much a part of our lives. We needed to feel it and touch it. Without it we could lose the feeling of security, of possession that paper confers. Then we moved on into the control room of the new plant. There was no paper in sight, only banks of electronic screens! I felt as though I were talking to the captain of the ***Thomas Lawson.*** This manager didn't understand that the limits of printing on paper as a technology for conveying information were not far away and that electronic technology would soon be able to convey information more effectively and cheaply.

If you are at the limit, no matter how hard you try you cannot make progress. As you approach limits, the cost of making progress accelerates dramatically. Therefore, knowing the limit is crucial for a company if it is to anticipate change or at least stop pouring money into something that can't be improved. The problem for most companies is that they never know their limits. They do not systematically seek the one beacon in the night storm that will tell them just how far they can improve their products and processes.

That's not always the case. It was an understanding of the limits of its current technologies that persuaded IBM to develop a new semiconductor packaging technology for the 4300 and 308X series of computers that they introduced in the late 70s; persuaded Bell Labs along with Corning to be the first to develop fiber optic cables for telecommunication in the 60s; and persuaded Sir James Black to reject the conventional screening approach for new drugs to come up with Tagamet for ulcers, which then put Smith Kline into a lead-

ership position. As T. R. Reid described in ***The Chip,"*** it was an understanding of the "tyranny of numbers," the limits of connecting wires, that convinced Noyce and Kilby to develop a new process and product that eventually became the semiconductor chips that permeate so much of our lives today. At the time it was hard for outsiders to see why these companies and men abandoned their past successes. But the outsiders didn't understand limits.

For those who don't understand limits and the S-curve, change comes as a surprise, catching them on their blindside. It happens so often and predictably that I've often thought of calling the S-curve the "blindside curve." But this would emphasize the negative too much. The S-curve has a positive side too. Companies can and do use it as the basis for successful attacks. Indeed, we could call it the "attacker's curve" too. So let's leave it as the S-curve, a literal name for its shape.

THE ATTACKER'S ADVANTAGE

For the S-curve to have practical significance there must be technological change in the wind. That is, one competitor must be nearing its limits, while others, perhaps less experienced, are exploring alternative technologies with higher limits. But this is almost always the case. I call the periods of change from one group of products or processes to another, technological discontinuities. There is a break between the S-curves and a new one begins to form. Not from the same knowledge that underlays the old one but from an entirely

* Reid, T. R., The ***Chip: The Microelectronics Revolution and the Men*** Who ***Made It,*** New York: Simon & Schuster, 1985.

new and different knowledge base. For example, the switch from vacuum tubes to semiconductors, the switch from propeller-driven planes to jets, the switch from natural to synthetic detergents or fibers, the shift from cloth to paper diapers, the switch from records to tapes to compact discs, the switch from carbonated cola drinks to carbonated juice drinks, and even the shift from conventional tennis racquets to the Prince racquet with its enlarged "sweet spot." These are all technological discontinuities. And they have all unseated industry leaders.

Technological discontinuities have been and will be arriving with increasing frequency. The scientific knowledge that underpins our products and processes is multiplying by leaps and bounds in fields as diverse as quantum physics, surface chemistry, cell biology, mathematics and the structure of knowledge itself. Furthermore, every day we learn more about the process of innovation-how it works and how it can be made to work better. These two developments aren't new, but never before have they interacted in such a way to produce the explosion of knowledge and change that is taking place today. Thus, it's my feeling that as much as 80 percent of all manufacturing industries and a large portion of all service industries will see major technological changes before the year 2000. We are living in an age of discontinuity, and in an age in which the risk to industry leaders has never been greater.

The results of a discontinuity are almost always brutal for the defender. The failure to recognize the limits of electromechanical cash registers at NCR cost thousands of workers and executives their jobs. It cost NCR's investors millions of dollars as well. For Unilever it meant months spent scrambling to produce their own synthetic detergents all the while losing the lead to P&G. For our paper maker in Alabama it

may mean underutilized plant capacity and depressed prices if electronics reduces the need for paper.

My thesis is not only that technological discontinuities will come with increasing frequency as we move toward A.D. 2000, but that during these discontinuities the attackers will have the advantage over the defenders.

As limits are reached, it becomes increasingly expensive to make progress. At the same time, the possibility of new approaches often emerges—new possibilities that frequently depend on skills not well developed in leader companies. As these attacks are launched, they are often unnoticed by the leader, hidden from view by conventional economic analysis. When the youthful attacker is strong he is quite prepared for battle by virtue of success and training in market niches. The defender, lulled by the security of strong economic performance for a long time and by conventional management wisdom that encourages him to stay his course, and buoyed by faith in evolutionary change, finds it's too late to respond. The final battle is swift and the leader loses. His attempts to defend his employees and shareholders fail. Doomed by doing too little, too late.

In order to overcome the attacker's advantage, defending companies must understand the S-curve and limits, because they will tell management when an attack can occur and what its consequences might be. They will thus help defenders anticipate and deal with their challengers.

A NEW PARADIGM

This is not a theory. Companies have used these insights either implicitly or explicitly to get the jump on competition. For example, Procter & Gamble not only exploited synthetic

detergents but also exploited opportunities in paper processing to come up with Pampers. Pampers now accounts for 35 percent of disposable diaper sales and more than 20 percent of P&G's profits. P&G is trying to do it again with their new process for making orange juice. Michelin captured 11 percent of the U.S. tire market when it introduced radials, which produced longer tire life. Citibank put its competitors on the defense when it introduced its automated tellers. Sony and other companies may eventually capture the recorded music market with the introduction of the compact disc that provides much more realistic sound than audio tape. Smith Kline ensured its place as the number-one-ranked pharmaceutical company in terms of earnings and earnings growth when it introduced Tagamet for ulcer treatment, again a product based on a new technology. Johnson & Johnson did it with Tylenol. The Japanese gained an advantage over the Swiss with digital watches. GE did it to its competitors in jet engines with the high by-pass fan jet. Texas Instruments did it to Westinghouse, Sylvania and several other established companies when it captured the lead in solid-state electronics. Harris Intertype Corporation saved itself back in the mid-60s by switching from the maturing electromechanical typesetting technology to electronics. Xerox did it to the carbon paper makers during the 60s by developing its inherently more flexible and cheaper copying and duplicating process. U.S. Surgical did it in surgery by exploiting the potential of staples to close wounds, a procedure developed by the Russians. IBM took the lead from Smith Corona in the office by developing electric typewriters, which have subsequently become computer-based word processors. In each case an emerging technological opportunity, juxtaposed with a maturing but still improvable traditional technology, provided

an opportunity for a new competitor to grab leadership from an existing one.

If you look at the business landscape with this new paradigm and perspective of S-curves, limits and the attacker's advantage, you will see other marketplace battles shaping up. The makers of electronic cameras that put images on magnetic media could challenge the now dominant technology of chemical processing of pictures. Fotomats would be a thing of the past. Soft drinks based on juices developed with the aid of biotechnology may challenge colas. Specially bred plants resistant to insects and other pests will change the need for herbicides and insecticides now made by chemical companies. Parallel processing computers will challenge conventional serial processing computers and their makers. Indeed, makers of light-based computers may challenge makers of electron-based computers like IBM and DEC; and a new material called gallium arsenide may take a hunk of the silicon semiconductor market from its makers. Magnetic resonance imaging technologies will replace the need for computer aided tomography (CAT scans) in medical diagnosis. Monoclonal antibodies may turn out to be a safe and more effective substitute in cancer therapy for radiation and all its ill effects. New companies may exploit the potential of biotechnology to produce drugs that do not act directly, but rather stimulate the body's production of "natural" drugs which have no side effects. Home banking based on electronics may continue to replace the need for branch expansion at the major money center banks. The list can go on and on. The questions are which of these changes will occur and when. I don't have the answers, but it's possible to get them by doing the right analysis with S-curves and understanding limits.

In short, these ideas will give the reader a new understanding of competition. Needless to say the S-curves, limits analyses and other techniques described in this book can be misused. Mistakes can be made, even by scientists, about limits-particularly the limits of a competitor's technologies. Even if the limits are clearly defined, the breakthrough idea about how to reach them may be missing. Internal processes may be slower and more cumbersome than estimated, causing big increases in the cost of pushing a technology to its limit, These problems may lead to incorrect diagnosis of what the future holds and misguided actions. But if these mistakes are avoided, and they can be avoided most of the time, the S-curve will provide a solid base for thinking about what will happen in the future, and doing what is necessary to capitalize on opportunities.

Despite the fact that S-curves, limits analyses, and the attacker's advantage are concepts that are not simple to apply, they help to explain a number of ideas that often go against conventional management wisdom. Why leaders lose. Why there are no static advantages in business, and why individual products lose a competitive position faster than we expect.

Why small competitors often get the drop on large competitors. And why corporate leaders who attempt to control the pace of innovation in their industry almost always fail.

Consider the advice "stick to your knitting." Bob Waterman, who co-authored In Search of ***Excellence,*** wrote there that a corporation's success is based on the unique set of competitive skills it has honed over the years. Thus, he argued, it is best for it to stay close to home and not move into new fields. But what about when a company is near the limits of its ability to improve its products as NCR was in 1971? What should it do then? Curtiss-Wright tried staying with

propeller aircraft long after the introduction of jets and is now just a shadow of its long-standing competitors Lockheed and McDonnell Douglas. Likewise, Addressograph-Multigraph, the maker of office products, stuck with mechanical machines that couldn't keep pace with electronic counterparts. In short, when it comes to technology the best strategy may be to do the unfamiliar. Move away from familiar areas into less familiar ones, as Harris, Corning and Gould have done. A frightening prospect personally and professionally.

THE COURAGE TO CHANGE

The S-curve, limits and attacker's advantages are at the heart of these problems and they also provide the key to solving them. For example, there are people, call them limitists, who have an unusual ability to recognize limits and ways around them. They ought to be hired or promoted. There are others who can spot ways to circumvent limits by switching to new approaches. They are essential too. Imaginary products need to be designed to understand when a competitive threat is likely to become a reality. Hybrid products that seem to be messy assemblages of old and new technologies (like steamships with sails) can sometimes be essential for competitive success. Companies can set up separate divisions to produce new technologies and products to compete with old ones. S-curves can be sketched and used to anticipate trouble.

None of this is easy. And it won't happen unless the chief executive replaces his search for efficiency with a quest for competitiveness. Indeed it is the chief executive who has the major role to play in making sure his company rides the wave of technology that continues to hit us. He need not be a

scientist, but he must be someone who understands how science and innovation develop, someone with the conviction to insist that the company abandon its technology and skill base when everything in classic economic terms is going well, someone with a thick skin to endure the criticism that will come when the first steps toward new products and processes inevitably go astray or prove disappointing.

Top management has to develop a language and a facility for talking about and directing technology. We don't hear about technology in the boardroom, except for some progress reports that we pretend to understand or criticize, because we don't have a language or conceptual framework for managing technology. There have been several theories proposed to help management "link" technology with the market by charting a company's strength in a particular technology against its market potential, but the link is often only visual and superficial. Indeed there is no understanding of the linkage. That is what this book hopes to do-establish the linkage and the language management needs in an era driven by technological discontinuity and international competition.

Most top executives understand, I think, that technological change is relevant to them and that it is useless and misleading to label their business as high-tech or low-tech. What they don't have is a picture of the engines of the process by which technology is transformed into competitive advantage and how they can thus get their hands on the throttle.

Because they lack the language and the right questions, they can't answer the big questions: How much trouble is my company really in? Does this new product or process represent a real threat? What is the long-term verdict? In the middle of the competitive battle when there is smoke on the

field and people and products are falling over, that is what they need to know.

Understanding S-curves, the way they unfold and what will limit them, is key to diagnosing just how fatal is the trouble you are in. And how big an opportunity might be out there. These curves need not be drawn in retrospect. They can be sketched now. Precision isn't as important as point of view. It's enough to know the rough shape of a technology's approach in order to make good judgments. If change occurs at the time learning starts to slow, wrote Phillip Moffitt recently in ***Esquire,*** "**. . .** then there is a chance to avoid the dramatic deterioration. If we call this the 'observation point,' when you can see the past and the future, then there is time to reconsider what one is doing."*

That's what has been missing. Perhaps that's why so many executives have lacked the will to manage technology and have retreated to the position that technological developments are unpredictable and unmanageable.

My observation and that of my McKinsey colleagues is that even when top managers understand what is necessary to stay ahead, only a handful have the conviction and discipline to act on that understanding. Only a few have the will to change and have led their companies through technological discontinuities. In fact they have made them happen. The question is how many of us can follow their lead and avoid the fate of the ***Thomas Lawson.***

* Moffitt, Phillip, "The Dark Side of Excellence," ***Esquire,*** December 1985, pp. 43-44.