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第一節

管理科學評論 試題

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〔試題完〕

In Question Perspectives on business issues-in-progress



The old scientific management was about ensuring control. The new will be about making sense out of chaos.

Is Management Still a Science?

by David H. Freedman

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As every manager knows, new technologies are transforming products, markets, business process, and entire industries, revolutionizing the business environment. Yet the more technology looms as a factor of competition, the more the emphasis in managerial books, executive education classes, and corporate training seminars is on the “soft” arts of leadership, change management, and employee motivation. In other words, the more science and technology reshape the very essence of business, the less useful the concept of management itself as a science seems to be.

On reflection, this paradox isn't so surprising. The traditional scientific approach to management promised to provide managers with the capacity to analyze, predict, and control the behavior of the complex organizations they led. But the world most managers currently inhabit often appears to be unpredictable, uncertain, and even uncontrollable.

Not so long ago, for example, Compaq Computer was everybody's model of a lean, dynamic start-up that could successfully do battle with sluggish giant IBM. But that was before mail-order clone-makers like Dell and Northgate arrived on the scene. Now yesterday's start-up is today's sluggish giant, and Compaq faces the painful task of recreating itself in a radically changed competitive environment.

In the face of this more dynamic and volatile business world, the traditional mechanisms of "scientific management" seem not only less useful but positively counterproductive. And science itself appears less and less relevant to the practical concerns of managers.

However, the problem may lie less in the shortcomings of a scientific approach to management than in managers' understanding of science. What most managers think of as scientific management is based on a conception of science that few current scientists would defend. What's more, just as managers have become preoccupied with the volatility of the business environment, scientists have also become preoccupied with the inherent volatility of nature and with the dynamics of unpredictable and unstable systems in the natural world.

Put simply, while traditional science focused on analysis, prediction, and control, the new science emphasizes chaos and complexity. Today scientists are developing powerful descriptions of the ways complex systems – from swarms of mosquitoes to computer programs to futures traders in commodities markets – cope effectively with uncertainty and rapid change.

And therein lies an opportunity for fruitful dialogue between the world of management and the world of science. The new rules of complex behavior that cutting-edge scientific research describes have intriguing parallels with the organizational behavior many companies are trying to encourage. Science, long esteemed by business as a source of technological innovation, may ultimately prove of greatest value to managers as a source of technological innovation, may ultimately prove of greatest value to managers as a source for something else: useful new ways of looking at the world.

The wide-ranging texts reviewed here suggest the broad outlines of what might become the new scientific management. Their message: management may indeed be a science - but not the science that most managers think.

The Science Behind Scientific Management

To understand the implications of the new science for management start with the book that coined the term "scientific management." In 1911, the turn-of-the-century industrial engineer Frederick Winslow Taylor published his magnum opus, *The Principles of Scientific Management*, which laid out his ground rules for efficient industrial organization. Taylor's book is now a classic of managerial literature. His ideas have shaped companies across the industrial spectrum and defined the task of management for generations of managers.

Taylor's book was profoundly influenced by the concerns of the science - particularly the physics - of his time. In the nineteenth century, Newton's laws of motion were first used to analyze the forces exerted on and by complex physical systems, allowing scientists to predict the behavior of those systems. Meanwhile, the principles of thermodynamics, elucidated in the second half of the nineteenth century, provided the one missing ingredient - heat interactions - needed to complete Newton's conception of the physical world. Together these theories allowed scientists to calculate how machines could function with maximum efficiency.

From the opening pages of his book, Taylor was preoccupied with the problem of efficiency as it applies to organizations. When it comes to natural resources, he argued, people clearly understand the need for efficiency because "we can see and feel the waste of material things." But "our larger wastes of human effort," brought on by the "awkward, inefficient, or ill-directed movements of men," are "less visible, less tangible, and...but vaguely appreciated."

**On Science and
Management**

**The Principles of Scientific
Management**

by Frederick Winslow Taylor New
York: Harper, 1911

Chaos: Making a New Science

by James Gleick
New York: Viking, 1987

**Complexity: Life at the Edge of
Chaos**

by M. Mitchell Waldrop
New York: Simon & Schuster, 1992

The Fifth Discipline: The Art and Practice of the Learning Organization

by Peter M. Senge

New York:Doubleday, 1990.

According to Taylor, the fundamental cause of this waste of human effort was unscientific management. In other words, he thought managers focused too much on the output of work and not enough on the processes by which the work was done. In most turn-of-the-century workplaces, managers paid workers for predetermined outputs, usually through some type of "piecework" system, then left it to work crews to determine the actual methods of the work. Taylor disparaged this approach, calling it the "initiative and incentive" system. "It is only by giving a special inducement or 'incentive'... that the employer can hope even approximately to get the 'initiative' of his workmen."

It's ironic to read Taylor's criticisms today, when so much emphasis has been placed on encouraging employee initiative on the job and on crafting incentive systems that "pay for performance." Still, there were good reasons for why Taylor saw "initiative" and "incentive" as part of the problem rather than part of the solution. As long as the managers of his day depended on work groups to decide how work was done, they had no way to directly influence the efficiency of the organization. Indeed, traditional management was an inherently unstable system, which forced managers either to rely on coercion or to abdicate their authority altogether. For example, one common way managers tried to boost productivity was by regularly raising piece rates once most workers met them. But this only induced workers to engage in "soldiering" – that is, to limit their output intentionally in order not to undermine established rates.

Taylor's solution was "the substitution of a science for the individual judgment of the workman." Managers were to separate the planning of work from its actual execution and reserve for themselves the choice of methods by which a particular task was done. By analyzing all of the steps in a work process and creating standardized procedures for each step, managers could identify the "one best method" for performing a task that would guarantee maximum efficiency. "The best management is a true science," Taylor wrote, "resting upon clearly defined laws, rules, and principles as a foundation." And those laws constituted an understandable, predictable, controllable system. "In the past the man has been first; in the future the system must be first."

In effect, Taylor urged the individual manager to think of himself as a scientist who alone understands the fundamental laws of the system he is studying. For Taylor, the worker played a passive role, almost as if he were part of the apparatus of the experiment. Over and over again in his book, Taylor repeated this "general principle": No matter what the job or how seemingly simple the task, "the science which underlies each workman's act is so great and amounts to so much that the workman who is best suited actually to do the work is incapable (either through lack of education or through insufficient mental capacity) to understand the science." It is only the manager, armed with a scientific predisposition to "search for general laws or rules," who can understand the true science of work.

But this is not to say that Taylor ignored the issue of employee motivation or the psychological dimension of work. On the contrary, a major part of *The Principles of Scientific Management* concerns "the accurate study of the motives which influence men." That is, for scientific management to be successful on Taylor's terms, managers must do more than just analyze and reorganize work. They need to effect "a complete revolution in the mental attitude" of the worker.

Yet even here Taylor reflected the scientific assumptions of his day – particularly the belief that "the motives which influence men" can be reduced through scientific analysis and control in the same way that the physical activities of shoveling iron or cutting metal can be. In discussing employee motivation, Taylor noted, "At first, it may appear that this is a matter for individual observation and

In fast-changing markets, Taylor's "scientific" principles are a recipe for disaster.

judgment and is not a proper subject for exact scientific experiments." But while psychological laws are more complicated and subject to exceptions, "owing to the fact that a very complex organism – them human being – is being experimented with," Taylor maintained that "laws of this kind, which apply to a large majority of men,

unquestionably exist and when clearly defined are of great value as a guide in dealing with men."

After such lofty language, some of Taylor's actual suggestions are selfevident. For example, he insisted that productivity improvements based on scientific management be shared with workers in higher wages; otherwise they won't cooperate in work reorganization. Other suggestions of his are crude and simplistic, like this major piece of advice: Never deal with workers as a group, only deal with one individual at a time. "When men work in gangs, their individual efficiency falls almost invariably down to or below the level of the worst man in the gang." Taylor's

solution was to have workers assigned individual tasks that they were to perform in the greatest possible isolation.

But whatever one thinks of his specific suggestions, they all share the nineteenth-century scientific regard for reductionism: breaking down things into isolated parts in order to better control them. Indeed, all of the techniques of scientific management – the planning department, time-and-motion study, standardization of methods and tools, and the like – are so many means to this end. But Taylor urged his readers not to confuse the techniques with the basic scientific principles. "It is only through *enforced* standardization of methods, *enforced* adoption of the best implements and working conditions, and *enforced* cooperation that this faster work can be assured. And the duty of enforcing the adoption of standards and enforcing this cooperation rests with the *management* alone."

Frederick Taylor's principles inaugurated a revolution in management and in the organization of work. In the decades after his book's publication, Taylor's ideas contributed to massive increases in productivity and the standard of living. However, the experience of the last 20 years has taught managers that in a new business environment such "scientific" principles are a recipe for disaster. In fast-changing markets, the fragmentation of work, the separation of planning from execution, and the isolation of workers from each other create rigid organizations that can't adapt quickly to change. As a result, managers must now rethink the fundamental elements of Taylor's system: work organization, employee motivation, and the task:of management.

The majority of new managerial ideas – like crossfunctional teams, self-managed work groups, and the networked organization – are either direct or indirect responses to the inadequacies of Taylor's original model. Yet for all of the proliferation of specific techniques, the fundamental principles of a new managerial paradigm are far from clear.

At this current crossroads, recent developments in science may prove helpful. Even as Taylor was codifying his own organizational systems, scientists were beginning to understand the shortcomings of the nineteenth-century scientific models on which that system was based. Within a decade of the publication of Taylor's book, new developments in physics - Einstein's relativity theory and quantum mechanics – suggested that at the extremes of space and time, from the universe in its entirety to subatomic particles, the laws of Newtonian physics broke down. And more recently, scientists have extended that message of uncertainty and unpredictability to the everyday world.



According to Taylor, managers should deal with workers individually – never collectively.

Coping with Chaos and Complexity

Nineteenth-century physics, based on Newton's laws of motion, posited a neat correspondence between cause and effect. Scientists were confident that they could reduce even the most complex behaviors to the interactions of a few simple laws and then calculate the exact behavior of any physical system far into the future. This conviction profoundly shaped Taylor's analysis of organizations and of that "very complex organism," the human being at work. But during the past few decades, more and more scientists have concluded that this and many other of science's traditional assumptions about the way nature operates are fundamentally wrong. Far from being as predictable as clockwork, nature appears as random as a throw of the dice.

"Chaos theory" is the general term for this new model of how things work, and probably the best introduction to it is the best-selling book *Chaos* by science writer James Gleick. According to Gleick, the chief catalyst for chaos theory was the research of MIT meteorological scientist Edward Lorenz. In the early 1960s, Lorenz developed a computer program that simulated a weather system. By plugging in numbers representing the initial state of winds and temperatures, Lorenz's program churned out the subsequent weather pattern as it evolved over time. Lorenz, like most scientists, assumed that small changes in the initial conditions he fed into the computer would result in correspondingly small changes in the evolution of the entire system. To his surprise, he discovered that even the most minuscule of changes caused drastic alterations in the weather pattern. In effect, a slight breeze in Idaho or a one-degree drop in temperature in Massachusetts could end up changing balmy weather in Florida into a hurricane a month later.

The effect defied both intuition and what meteorologists had previously understood about their science. Intrigued by Lorenz's puzzle, scientists from a wide variety of fields began experimenting with simulations of other physical systems,

only to discover the identical phenomenon. An infinitesimal change in initial conditions could have a profound effect on the evolution of the entire system. Take the simple example of water dripping from a faucet. Speed up the rate of flow ever so slightly, and the pattern by which drops fall changes radically. Repeat the experiment again, and the pattern will be completely different. What's more, the pattern of drip formation changes in ways that no one can model. Even the most powerful supercomputer can't predict when the next drip will fall.

What is true for the weather and a dripping faucet has proved equally true for the vast majority of physical systems. A slight shift in temperature causes sudden turbulence in a pan of water. A tiny accumulation of charge triggers a lightning bolt. A small shift in the fertility rate doubles the population of a community of gypsy moths.

This basic insight – that minute changes can lead to radical deviations in the behavior of a natural system – has inaugurated an equally radical shift in how scientists see the world. Put simply, the nineteenth-century emphasis on predictability and control has given way to a late twentieth-century appreciation for the power of randomness and chance. For all practical purposes, the behavior of even relatively simple physical systems is fundamentally unpredictable.

But this is not to say that chaotic systems don't have any patterns. While the idea that nature is fundamentally random is counterintuitive, chaos theory's second basic insight is even more so: that patterns do lurk beneath the seemingly random behavior of these systems. In fact, systems don't end up just anywhere; certain paths apparently make more sense – or at least occur much more frequently – and chaos theorists call such paths "strange attractors." Thus while meteorologists can't say with certainty what the weather will be on a particular day in the future, they can estimate the probability of the kind of weather likely to occur. In other words, strange attractors allow scientists to determine within broad statistical parameters what a system is likely to do – but never exactly when a system is likely to do it. The cause-and-effect precision of traditional physics has been replaced by the statistical estimate of probabilities.

In addition, the *way* scientists identify the predictable patterns in a system has been turned on its head. Instead of trying to break down a system into its component parts and analyze the behaviors of those parts independently – the reductionist tradition that so influenced Taylor—many scientists have had to learn a more holistic approach. They focus increasingly on the dynamics of the overall system. Rather than attempting to explain how order is designed into the parts of a system, they now emphasize how order emerges from the interaction of those parts as a whole.

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The quest to gain insight into and make use of the order that emerges from chaotic systems is the subject of *Complexity*, M. Mitchell Waldrop's upcoming book. Waldrop, a contributing correspondent of *Science* magazine, describes some recent research

from the Santa Fe Institute, a New Mexico think tank specializing in the analysis of "self-organizing" systems. The institute has brought together an eclectic group of scientists who focus on the ways that the simple actions of independent components can combine to produce extremely complex behaviors, even in the absence of any central intelligence or control. Santa Fe chemists, for example, are examining how molecules organize themselves into self-reproducing proteins. Biologists are determining how cells arrange themselves into immune systems. And economists are considering how the limited actions of individual buyers and sellers form complex markets, industries, and economies.

Complexity
researchers view
the economy
as organic – not
as a machine.

In the process, the Santa Fe researchers have developed some basic rules for what Waldrop calls "complex adaptive systems." These systems, Waldrop claims, are among the most successful in nature. Some examples include the ecology of tropical rain forests, colonies of ants, and even the human

brain.

Such systems have several characteristics in common. First, they are "self-managed" -- that is, they consist of a network of "agents" that act independently of one another and without guidance from any central control. For example, each one of the brain's roughly 100 billion neurons is a kind of miniature chemical computer that follows its own independent pattern of behavior. Take a neuron out of the brain, and it can still function. There is no "master neuron" or central area of the brain that controls what each neuron does.

Yet these agents are capable of engaging in cooperative behavior. They can form groups or "communities" that cooperate in producing higher-order behaviors that no single agent could accomplish on its own. In the brain, each neuron is connected to millions of others. Some communities of neurons, clustered in particular areas of the brain, specialize in functions such as language or visual recognition. It is precisely the interactions among neurons that produce human intelligence. For example, the structural difference between individual squid

neurons and human neurons is relatively small. However, a human brain not only contains many more neurons than a squid's but also the organization of its neurons is much more complex and interwoven. A particular kind of feedback makes self-management possible. In a sense, self-organizing systems are learning systems but of a specific sort. Capable of "learning" through feedback from the external environment, they also "embed" that learning in their actual structure. For instance, the more a set of neurons is involved in some piece of mental work--like recognizing a face or solving a mathematical problem – the stronger the actual chemical connection among the neurons (and the easier for the brain to make the connection the next time). Indeed, the human brain is forever reconfiguring the connections between neurons in response to external and internal stimuli. In this way, self-organizing systems constantly rearrange themselves as the effects of previous actions or changes in external conditions ripple through the system. Information is embedded in structure. As external conditions change, the structure of the system automatically changes.

Finally, self-management and learning through feedback allow these systems to operate by "flexible specialization." Self-organizing systems usually contain an array of specialized behavioral niches occupied by specific agents or groups of agents. However, old niches constantly disappear and new ones are created as the external environment changes. Therefore, agents aren't permanently locked into previously useful behaviors that have since become obsolete, which helps the system as a whole adapt to change. Waldrop notes that self-organizing systems tend to change so rapidly and so completely that it becomes meaningless to talk about agents or groups of agents "optimizing" (a term redolent of the nineteenth-century focus on efficiency) their behavior. Rather, such systems are characterized by what Waldrop calls "perpetual novelty."

In general, the complex adaptive systems found in nature contain individual agents that network to create self-managed but highly organized behavior; respond to feedback from the environment and adjust their behavior accordingly; learn from experience and embed that learning in the very structure of the system; and reap the advantages of specialization without getting stuck in rigidity. If these characteristics sound familiar, it's because they so closely match the new kind of organization many managers are struggling to create in order to cope with a more uncertain – and frequently chaotic – business environment.

According to Waldrop, few complexity researchers have applied the concepts of their emerging field to the specific organizational problems managers face. But one area of research at the Santa Fe Institute takes a step in that direction. Economists at the institute are creating computer simulations of economic transactions much as

Lorenz simulated weather systems some 30 years ago. Their goal is to model complex market behaviors by constructing them from the interaction of a limited set of simple building blocks. "Instead of viewing the economy as some kind of Newtonian machine," writes Waldrop, "they would see it as something organic, adaptive, surprising, and alive."

Simulating economic behavior isn't easy. Although programmers need only model the simple behaviors of individual agents and then let self-organization do the rest, it's not always clear which simple behavior will result in a simulation that accurately reflects reality. So far, the Santa Fe researchers haven't come up with a convincing computer version of an entire economy. They have, however, developed simulations; that represent limited aspects of economic activity, and some of these simulations have produced quite realistic behaviors.

One program, for example, simulates the stock market. It consists of agents that decide when to buy or sell stock. As in real stock markets, the actions of the computerized "traders" determine the price of the stock. At first traders made decisions randomly; but soon they came to buy and sell stock exactly as classical economic theory says they should -- according to the stock's fundamental value as set by its discount rate and dividend. Still later in the simulation, the agents "discovered" that by studying the history of a stock's price performance, they could make money by bidding a stock above and below its actual value. The result: the computer system learned to simulate the same kinds of bubbles and crashes that occur in real markets. Much as chaos theory has revealed the shortcomings of traditional physicists' mathematical models of the world, these simulations have pointed up the shortcomings of the elegant mathematical models of neoclassical economists.

For the Santa Fe researchers, the stock market simulation is just a start. They believe that if they can accurately simulate an entire economy, the computer system could be used, in the words of one scientist quoted by Waldrop, as a "flight simulator" for economic decision making. Such a program could estimate the probability of boom and bust cycles, simulate the effect of various government policies, or indicate what changes in consumer or business behavior might lead to more vital economies. In the meantime, one leading Santa Fe researcher has founded the Prediction Company, a commodities trading company that will make investment decisions with the help of a computerized trading simulator.

Toward a New Managerial Science

Chaos theorists and complexity scientists may not be studying business organizations, but their perspective has already shaped recent managerial literature. For an example consider one of the most popular managerial books of the last few

years, *The Fifth Discipline* by MIT researcher Peter Senge.

If Taylor's chief concern was inefficiency and waste, then Senge's is chaos and complexity -- and the loss of purpose that frequently comes in their wake. Most

Many managers are prisoners of the systems they're supposed to manage.

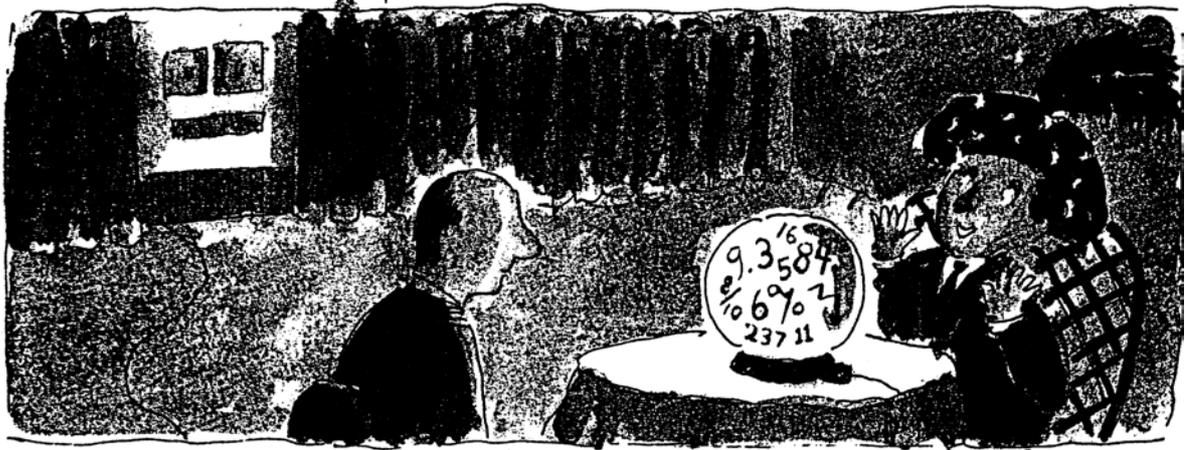
people, Senge argues, feel lost in the organizations of which they are a part. Managers are overwhelmed by too much information, too many rapid changes, and too many conflicting demands. "When asked what they do for a living," Senge writes, "most people describe the tasks they

perform every day, not the purpose of the greater enterprise in which they take part. Most see themselves within a 'system' over which they have little or no influence. They 'do their job,' put in their time, and try to cope with the forces outside of their control."

According to Senge, this systematic inability to cope with complexity is a direct result of traditional scientific approaches to management. From its opening sentences, *The Fifth Discipline* is an attack on the reductionism at the center of both Taylor's system and all of nineteenth-century science. "From a very early age," Senge notes, "we are taught to break apart problems, to fragment the world. This apparently makes complex tasks and subjects more manageable, but we pay a hidden, enormous price. We can no longer see the consequences of our actions; we lose our intrinsic sense of connection to a larger whole."

In a sense, managers are in a position rather similar to that of prechaos natural scientists. They *think* they understand the relationships between cause and effect in their organizations. But in fact, the links between actions and results are infinitely more complicated than most managers suspect. Senge calls this the "core learning dilemma" in organizations today: "We learn best from experience, but we never directly experience the consequences of many of our most important decisions."

As a result, managers are prisoners of the very systems they are supposed to manage. They understand neither the underlying dynamics of these systems nor how to influence those dynamics to achieve organizational goals. Indeed, the idea of the manager as an omniscient scientific planner is fundamentally misguided. According to Senge, "The perception that someone 'up there' is in control is based on an illusion -- the illusion that anyone could master the dynamic and detailed complexity of an organization from the top."



The Prediction Company will make investment decisions with the help of a computer simulation.

The alternative is to stop seeing an organization as a machine -- Taylor's mistake -- and to begin viewing it as a kind of living organism. This requires a holistic approach that reflects chaos theory's focus on the overall behavior of a system. "Living systems have integrity," Senge writes. "Their character depends on the whole. The same is true for organizations; to understand the most challenging managerial issues requires seeing the whole system that generates the issues."

"Systems thinking" is the fifth discipline of Senge's title; As he portrays it, systems thinking is the ability to understand the key interrelationships that influence behavior in complex systems over time – and should give managers the capacity for “seeing wholes.”

Consider Senge's story of a high-tech start-up from the 1960s, a case based on a number of real instances. After a few years of blistering growth, the company he calls WonderTech experienced a sudden dropoff in sales. Desperate to sustain growth, senior managers hired more salespeople and aggressively pushed marketing. These actions did increase sales as intended but only for awhile. WonderTech entered a period of volatile swings between high and low demand that eventually forced it into bankruptcy.

Chaos theory shows that small changes can have big effects.

In this case study, Senge traces the source of WonderTech's failure to management's ignorance of a few basic feedback processes. Put simply, high demand increased pressure on the company's production capacity. Inadequate capacity meant large backlogs of orders and long delays in delivery. Customers became angry and dissatisfied, which caused sales to drop.

As Senge tells the story, senior managers *did* understand that as sales grew, the company needed to invest in capacity. But as their fixed investments in

manufacturing increased, so did their need to keep sales up and their tendency to push sales and marketing to get more orders. Because the two sides of the organizational system -- sales and manufacturing-- were never in balance, the vicious circle of high growth, undercapacity, delayed delivery, and customer dissatisfaction repeated itself over and over again continually growing worse.

Senge notes that there are a limited number of such feedback processes at work in any organization, what he calls "systems archetypes." In a sense, they are the organizational equivalents of strange attractors in chaos theory: the basic patterns of behavior that occur in all organizations again and again

The WonderTech story illustrates a number of these archetypes. Senge's term for one of them is "limits to growth" -- the idea that any growth process produces the conditions for its own collapse. The more WonderTech focused on sales, the more it created a capacity problem that retarded sales. Senge calls another "shifting the burden" -- the idea that a short-term solution to a problem may actually make it worse by undermining an organization's ability to implement a more fundamental, long-term solution. Managers at WonderTech became so preoccupied with boosting sales that they were never able to focus on the real solution to their problem: expanding production capacity to control delivery time.

For Senge, it is precisely the systemic, automatic quality of these processes that accounts for the "out of control" feeling so many managers experience. Ignorant of the systems archetypes, they end up always seeing only the part, never the whole. In contemporary organizations, he argues, it is the work of managers -- and, indeed, everyone -- to understand the systemic processes driving human behavior and to change them: "The art of systems thinking lies in seeing through complexity to the underlying structures generating change."

When managers understand the dynamics of these archetypes and are able to make the deep connections between systems and behavior, they are in a position to effect real change. And just as chaos theory teaches that small changes can have big effects in physical systems, a crucial concept in systems theory is "leverage": the idea that "small, well-focused actions can sometimes produce significant, enduring improvements." In the WonderTech case, a simple commitment to rapid delivery -- a strategy managerial experts have since enshrined in the rubric "competing on time" -- would have done more to solve the company's problems than all the salespeople in the world.

If managers master systems thinking and the other disciplines Senge describes, the result is "the learning organization." As Senge portrays it, this learning organization has characteristics remarkably similar to the complex adaptive systems that scientists are discovering in nature. It is a highly decentralized system in which

any number of decision-making processes on the local level maintain order throughout and constantly adjust to change.

In effect, Senge's disciplines are meant to replicate in human organizations the organic control found in nature. One of the most interesting discussions in his book concerns the tools that some organizations are creating to help managers develop the skills they need to make organic control work. Take the example of microworlds, which are computer-based simulations of complex business situations based on the principles of systems thinking. With microworlds, managers can experiment with their organizations to reveal the largely hidden dynamics of complex systems, much as scientists use simulations of the weathers or water dripping from a faucet to learn how physical systems work.

At MIT's Sloan School, for example, first-year business students use a microworld simulating the rise and fall of People Express airline. With it, they explore the interrelated forces that, over a six-year period, caused People Express to lurch from one of the fastest growth rates in airline industry history to a sudden financial crisis and eventual purchase by a competitor. At the Hanover Insurance Company, managers train in a "claims learning laboratory" with microworlds that simulate the processes by which adjusters settle claims in the insurance industry. By allowing users to try out alternative approaches to solving business problems, such systems help managers to deepen their understanding of the systems of which they are a part. Microworlds also allow managers to recognize those strange attractors that may underlie behavior in all organizations and thus to identify high-leverage strategies for change.

As the language of "experiments" and "laboratories" suggests, Senge's new manager is every bit as much a scientist as Taylor's was – but, of course, a scientist of a very different sort. As Senge puts it, the scientific managers of today must be researchers who study their own organizations. And they must be designers who create the learning processes that make self-organizations possible, the processes that are essential to effective performance in a world characterized by perpetual novelty and change.