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A NEW PRODUCTIVITY PARADIGM FOR COMPETITIVE ADVANTAGE

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A decade of observed large differences in productivity driven competitive advantage cannot be explained by traditional productivity notions or conventional strategic analysis. We conclude on both empirical and theoretical grounds that most traditional sources of productivity have encountered diminishing marginal returns. Large competitive differences appear to arise from a new productivity source, nonlinear systems dynamics in business organizations. This has both theoretical and practical consequences for managing toward competitive advantage and requires a new approach to management, control, and organization.

OVERVIEW

The U.S. has suffered a steady decline in the growth of productivity for nearly three decades. The average output per hour in non-farm industry rose only 1.2 percent annually during the 1980s. Yet some organizations have experienced order-of-magnitude productivity gains, even in mature industries. These accumulating observations of differential productivity gains across a wide spectrum of businesses lead to two significant conclusions. First, most traditional sources of productivity improvement are becoming depleted or irrelevant. Second, a new area of productivity potential is being realized in organizations that see themselves as overlapping sets of dynamic, nonlinear systems. This perspective amounts to a productivity paradigm shift (Kuhn, 1962) from specialization to nonlinear dynamics; that is, chaos theory. It is the management of chaotic potential in business systems which results in quantum increases in productivity and competitive advantage.

Key words: Chaos, nonlinear dynamics, productivity, time

THE TRADITIONAL PRODUCTIVITY PARADIGM

Specialization

The essence of the traditional productivity paradigm is that productivity is a function of specialization. It was first articulated by Adam Smith in 1776 (Smith, 1986) in the manufacture of pins, and it still influences how work is organized throughout business organizations. Work is typically specialized by functions such as sales, marketing, engineering, manufacturing, purchasing, controlling, human resources, or finance. These are themselves further specialized. An assembly line, for instance, is a linear sequence of specialized work stations.

The specialization paradigm is deeply imbedded in both economic and managerial thinking. In the 1880s, George Frederick Taylor developed time and motion studies as a way to define and optimize separate units of specialized labor. His most famous early experience was steel mill

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materials handling, done then by men with shovels. Taylor made two observations. First, it was more efficient to station separate men by the various piles of iron ore, coal, and slag rather than move the same man around. This was true provided the mill was large enough to keep men busy at each pile. Second, it was more efficient to use a different size shovel at each pile, smaller ones for heavy iron ore so the men didn't tire as fast, and larger ones for lighter slag so that more material could be moved per motion. This made sense so long as shovels were sufficiently inexpensive compared with the labor cost saved by moving more total material per day per man. Both findings illustrate increased specialization, with manning supported by scale effects and differentiated shovels illustrating both learning and technological substitution. These are the usual productivity drivers within the traditional specialization paradigm.

The notion of a productive business as a sequence of specialized, individually managed and optimized activities is carried through most management practice today. Organization charts divide activities into specialized units. Educational curricula mirror basic specialization categories. Most managers' career tracks are within a specialty such as finance or manufacturing until they rise near the top of the organization. Even traditional accounting systems reflect the specialization paradigm. Total labor is the sum of labor at each sequential process step; total overhead is the sum of costs in specialized departments such as maintenance, accounting, or marketing.

Capital for labor, and scale

Specialization of labor enables other 'normal' productivity drivers. The most traditional has been the substitution of capital for labor. Capital substitution depends fundamentally on specialization, as physical capital is usually special purpose in use. Even general purpose computers or robots are programmed for specific tasks. Automation generally implies increasing task specialization, whether on transfer lines for machining cylinder heads or in chemical plant process modules. Productivity comes from scale effects as fixed capital costs are substituted for variable labor costs and amortized over sufficient volume to achieve a net economic gain.

There are two reasons that capital scale-derived productivity enhancement has diminished in today's mature industrial economies. First, many processes have reached physical or control limits. It is very difficult to make trucks longer or higher or wider given streets, corners, and overpasses. Second, many processes reach economic limits well before physical limits. A classic example is

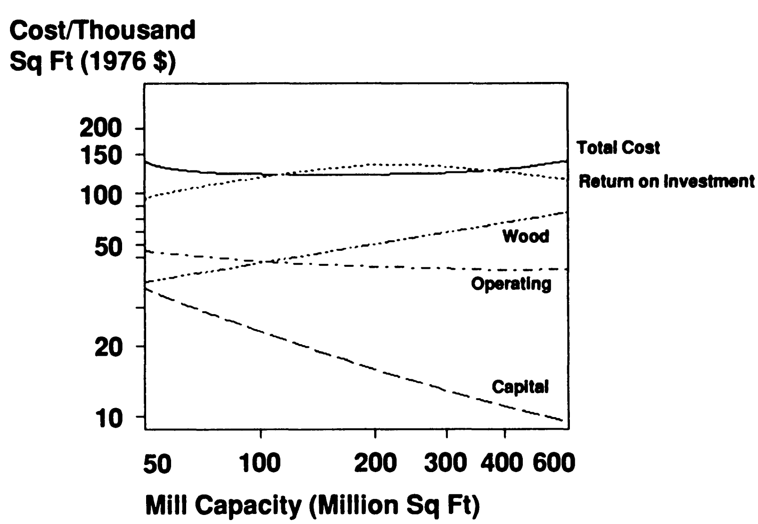


Figure 1. Plywood production economics. (Source: A major forest products company)

the woodshed constraint which limits southern yellow pine plywood mills to about 200 million square feet of annual capacity. Peeler blocks (logs greater than 8″ diameter and at least 8′ long) come from the forests around a mill. An increase in mill capacity must be provided from an expanded woodshed ring, all of which is subject to higher freight costs. Doubling mill size means the incremental wood supply is at least 41 percent more expensive at a constant transportation rate per unit distance. The actual economic scale limit imposed by woodshed geometry is given in Figure 1 for a sample of plywood mills.

Experience

In the 1940s learning curve phenomena were discovered in the production of B-17 bombers and Liberty ships. Focused repetition of complex work brought productivity improvement. This phenomenon culminated in The Boston Consulting Group's articulation of the generalized experience curve. All things being equal, total real costs of a given output decline between 20 and 30 percent for each doubling of accumulated experience (Noyce, 1977).

As with scale, experience effects are self-limiting. At any constant growth rate, the calendar time required to double experience and drive productivity increases with the log of the square of experience. This inherent slowdown in productivity is compounded when growth slows with market maturity.

Complexity

A separate further limit on both scale- and experience-derived productivity arises from the proliferation of products to serve smaller segments of a market, which often becomes necessary in order to achieve further scale and experience. Complexity is traditionally a drag on productivity, but hard to avoid as markets grow in size and sophistication—even Coca Cola now comes in a number of flavors and packages. Scale is harder to achieve with proliferating products, as shown for medical instrumentation in Figure 2.

Experience counts little when the product is constantly changing, as pointed out by several commentators (Abernathy and Wayne, 1974). This is graphically illustrated by Ford's automobile strategy in Figure 3.

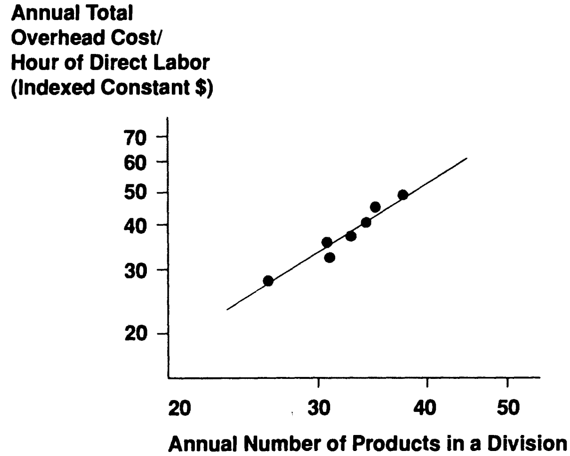


Figure 2. Scale and complexity: Electromedical equipment. (Source: Siemens)

Technology

The fourth traditional drive of productivity arising from specialization is technological substitution along lines first articulated by Joseph Schumpeter. New technologies substitute for less economic ones in (specialized) activities in the value chain. This source is, in the aggregate, subject to diminishing returns as technical advancement declines with increasing product or technological maturity. This is best seen on fairly long time scales. Figure 4 computes the cross-sectional rate of technical productivity improvement (energy efficiency × lamp lifetime) for all basic electric lighting technologies. They decline predictably with increasing technological maturity despite continuing advances in the underlying material sciences, physics, and chemistry supporting these products. The impact of technology here is independent of production scale and experience.

Additional evidence is given in Figure 5, which shows an experience curve time series of pneumatic tire productivity including changes in basic tire technology. Despite accelerating technology change, the economic productivity of tire manufacturing declines predictably with its accumulated experience curve, from seven percent from 1910–1920 to three percent today. Technological change may have enabled the experience effect, but did not enhance it or prevent diminishing marginal productivity returns.

Capital, scale, experience, and technology all derive from specialization, and are self-limiting

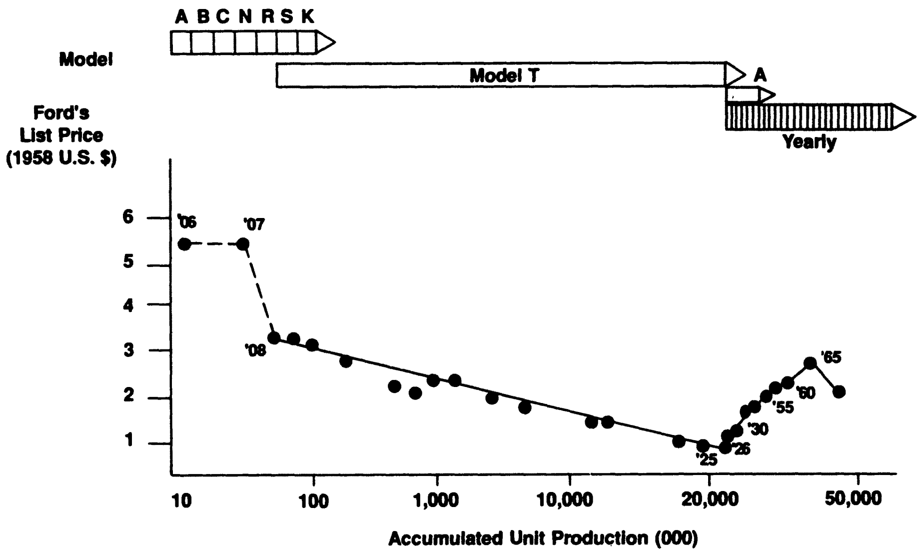


Figure 3. Experience and complexity: Ford Motor Company, 1900–1972. Adapted and reprinted by permission of *Harvard Business Review.* An exhibition from 'Limits of the Learning Curve' by William J. Abernathy and Kenneth Wayne, issue September–October 1974. Copyright © 1974 by the President and Fellows of Harvard College; all rights reserved.

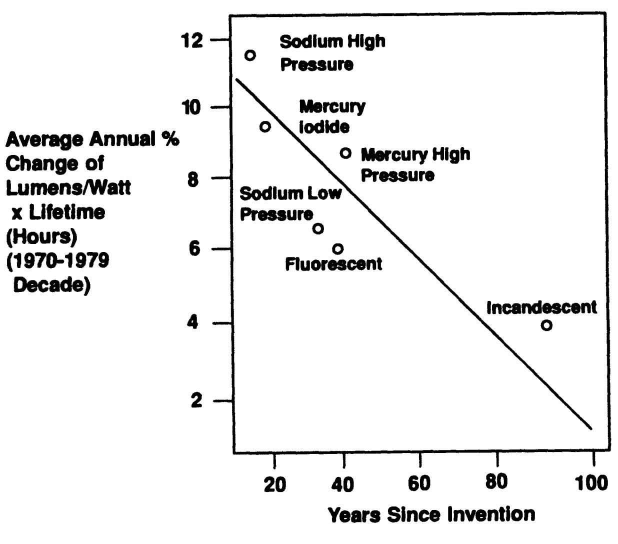


Figure 4. Maturing lamp technologies. (Source: Osram)

in their ability to further productivity gains. Gains are likely to be highest in newer products or technologies with rapidly expanding markets, low accumulated experience, and immature process and product technologies. The larger the base of existing economic activity, the less likely these conditions are to prevail in equivalent proportion to overall economic activity, and the more likely the negative drag of complexity. It follows that observed rates of productivity improvement have generally been declining for decades in maturing Western economies.

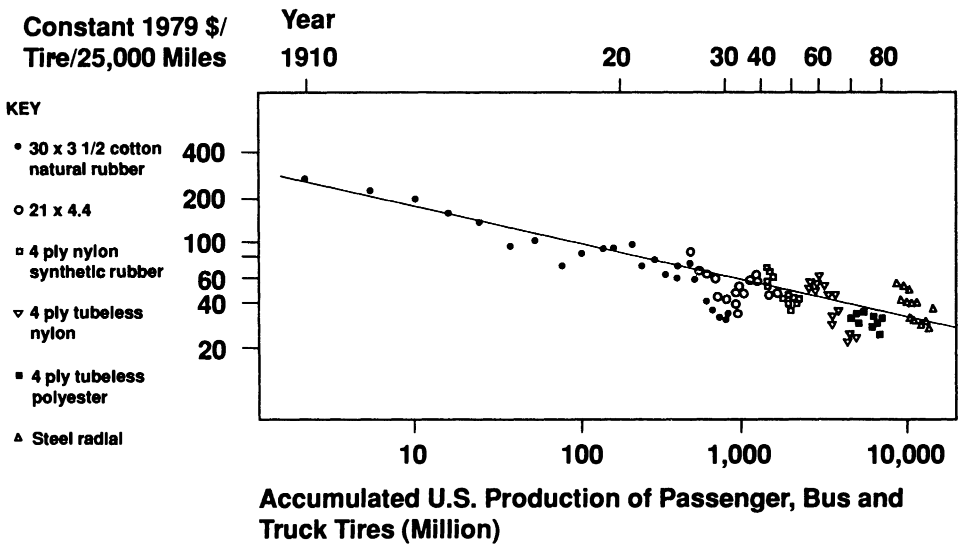


Figure 5. Pneumatic passenger car tires: U.S. wholesale price experience. (Source: BF Goodrich)

A NEW PRODUCTIVITY PARADIGM

Around 1980 we began to observe differential levels of productivity improvement that could not be explained by the traditional paradigm or any of its derivatives. Table 1 is representative of early data from four Japanese companies who compete globally in mature industries. On-site visits confirmed that none of these large, established companies had done anything extraordinary with plants or technology. Yet each of these organizations nearly doubled labor productivity, net asset productivity, and product line complexity simultaneously in about half a decade.

The traditional paradigm has difficulty explaining large simultaneous results in relatively mature products and markets. Substitution of capital for labor (and expansion of scale within facilities) might account for the observed labor productivity. But there was no corresponding expansion of aggregate volumes to support the underlying scale effects usually found with capital/labor substitution. Capital substitution should have reduced asset productivity absent major volume expansion. In the traditional paradigm, there is (at least theoretically) one route to simultaneous labor and asset productivity. That is to eliminate complexity by aggressively simplifying product lines. These companies didn't simplify; instead, they roughly doubled basic product line complexity. Under

Table 1. Typical performance improvements. Approximately 1976 to 1982

Company	Product	Total Labor Productivity	Net Asset Capital Complexity	Complexity (Product Lines)
Yanmar	Diesel engines	1.9×	2.0×	3.7×
Hitachi	Refrigeration equipment	1.8×	1.7×	1.3×
Komatsu	Construction equipment	1.8×	1.7×	1.8×
Toyo Kogyo	Cars, trucks	2.4×	1.9×	1.6×
Average		2.0×	1.8×	2.1×

Sources: Company interviews and estimates; Company literature conventional strategic cost perspectives, such a doubling should have driven up complexity costs substantially, possibly offset by capital, scale, or experience gains. The simultaneous improvements tend to rule this out.

We have found only one unifying explanation. *Simultaneous doubling of labor productivity, asset productivity, and complexity is an automatic consequence of halving cycle times, or equivalently doubling throughput rates*. An organization with doubled throughputs or halved cycle times will have twice the labor productivity per unit output provided labor can be suitably reduced or volumes appropriately increased (or some combination thereof). Doubling throughput also doubles capital productivity. Equivalent output can be produced by the same asset base in half the time, or with half the asset base in equivalent time. Heuristically, if everything is twice as fast then complexity is not a problem when doubling basic product variety. The new products don't interfere with the existing output. The additional variety can be produced 'in the second half of the year', that is, when labor and capital would both otherwise be unemployed.

Speed, by itself, is obviously a major source of productivity. Throughput acceleration has ordinarily been associated with the application of specialized capital—usually in the form of more advanced technology or control systems. In the companies cited—or any of hundreds of others we have visited that have become dramatically faster—this was not the primary enabler of speed. Much faster overall processes were achieved without accelerating individual value-added steps.

For example, both Komatsu and Yanmar use traditional transfer lines (specialized hard automation in the form of fixed tooling sequences to serially machine and convey complex parts), a familiar manufacturing example of specialization, scale, and technology. They run the many actual cutting tools on their transfer lines at about 2/3 of rated speeds, while U.S. practice has been to run them at or above rated speeds. The reason is a second order systems effect. Cutting tools wear out. To keep quality levels constant, the transfer line must be stopped and a tool replaced when any of them is sufficiently worn. They last about four times as long when run at 2/3 of rated speed. Slower speeds generate less shock, vibration, and heat, and let lubricants and chip removal systems work with large safety margins. The actual uptime of the line as a system can be increased from 60–65 percent (a U.S. company) to 85–90 percent (Komatsu) by slowing down each of the specialized tools in the transfer line system by 35 percent, for a net throughput gain of 15–20 percent.

We have found, in general, that productive systems have average throughputs much slower than theoretically possible with existing procedures, equipment, and controls. By productive systems, we mean the whole complex of activities producing a desired output including order gathering, information processing, actual production, and logistics. A wide range of experiences with cross-functional processes (among them the organizations sampled in Figures 6 and 7), suggest that the usual ratio of elapsed calendar time, which determines economic productivity, to actual value-added time, the point at which tool speeds, methods, capital, or technology must be changed, is more than 10:1. For example, a recent sample of processes from within IBM was over 20:1, which has led IBM to a major cycle time reduction initiative as part of their overall *M*arket *D*riven *Q*uality (MDQ) initiative. The causes of slowness are invariably numerous (and individually small) complex N^{th} order systems effects.

The strategic consequences derived from accelerated cycle times have received much recent attention from a practical business perspective (Bower and Hout, 1988; Merrills, 1989; Stalk, 1988; Stalk and Hout, 1990). Underlying the accomplishments of specific organizations, a new basic paradigm for the organization and management of work is emerging.

NONLINEAR DYNAMICS

The new productivity paradigm suggested by our research and practical experience is nonlinear dynamics. Most business processes are complex sequences of activities containing both positive and negative feedback loops. Sending something back to a previous activity to correct a problem introduces such a feedback loop. Almost all business processes are nonlinear because of such feedback loops. Moreover, most of these loops act with time delays, making the overall sequence not only nonlinear, but dynamic.

The specialization paradigm fails fundamentally in a nonlinear dynamic environment. Linear systems have two attributes essential for specialization to result in productivity gains. First, a linear system is the sum of its parts. Since the specialized activities are additively independent, they can be optimized separately and still achieve a global optimum. Second, increasing specialization usually enhances productivity, because only one incremental linkage (complexity) cost is incurred for each incremental specialization gain.

In a nonlinear dynamic system the global optimum is *not* the sum of local suboptima. No specialized activity manager, doing his utmost for productivity within his area, can know in isolation whether his action is helpful or harmful to the system. In a nonlinear dynamic system, increasing specialization increases the linkage costs (meetings, memos, telephone calls, materials handling) and time delays by roughly N factorial. No matter how small the individual linkage costs, increasing specialization will cause them to outweigh any productivity gains in even moderately complex nonlinear systems.

The nonlinear dynamics of linkage losses are most visible in the indirect costs of a business. Each data point in Figure 6 is an independent company or division, within a single plant, across a range of products and processes in North America, Asia, and Europe observed in 1987 as part of a global benchmarking exercise. The team taking the measurements included accountants and manufacturing engineers from a large U.S. component supplier. The data were obtained through on-site visits. All benchmarked organizations were measured as accurately as possible with respect to total employees and sales volume. Scale and complexity effects have been partly normalized by the number of product families per facility. Scale effects are still pronounced; doubling volume achieves about a 20 percent reduction in total indirect employees per million dollars of sales.

Three different management approaches are discernible in the survey. Those organizations with traditional management are the least productive, with remarkably consistent results along a range of products and organizational sizes. This group was characterized physically by process center manufacturing layouts, limited spans of control in rigid and highly detailed organizational hierarchies, and a lack of systems perspective by functional and process center managers. They are all divisions of old established public companies. The middle group are mostly private companies, about half of which are fairly recent

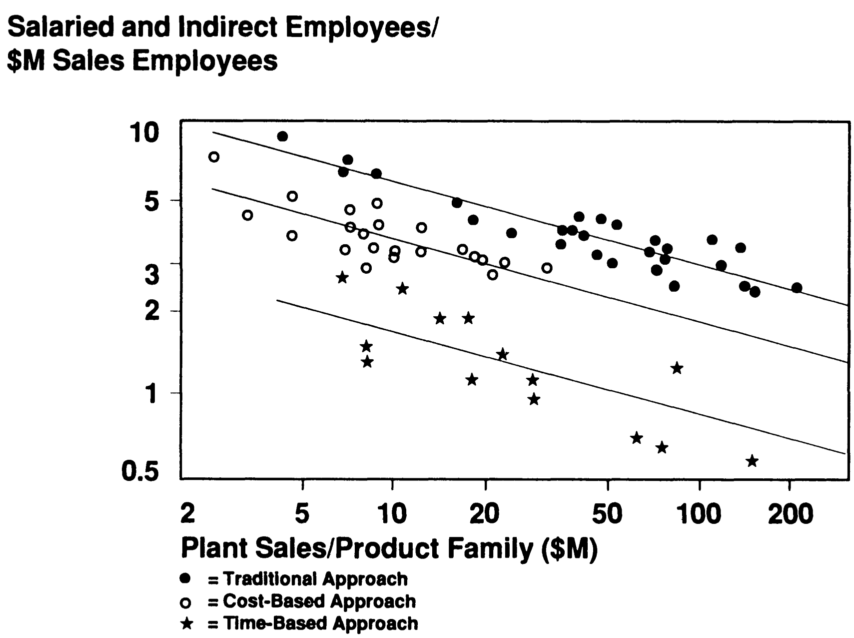


Figure 6. Automotive component suppliers

LBOs. They have dispensed with unnecessary (and perhaps even some necessary) indirect activities in order to pare costs to an absolute minimum. They typically carried high debt structures, were managed for cash flow rather than reported profits, and were characterized by wide spans of control in flattened hierarchies and an obvious reluctance to spend on items ranging from office amenities (no carpets) to basic research (no labs). This is about as far as the specialization paradigm can be pushed in terms of efficiency.

The third group are organizations that have speeded up significantly. They achieve comparable outputs with only 30 percent as much total indirect labor as traditional ones. The systematic attack on time characterizing the third group was directly observable in three ways. First, their response times to customers were much faster than the other two groups. Second, product lines were much broader. For example, one company in the third group with one third the total unit volume of the largest comparable supplier in the world (a division in the first group) had nearly four times the finished part numbers and 50 percent greater total labor productivity, all gained in indirect labor areas associated with complexity. Third, the field visits confirmed that the companies were managed according to a nonlinear dynamic systems paradigm, for example in the way middle managers could identify complete processes in the company, and the way they organized around processes rather than traditional functions.

This sample supports the hypothesis that specialization no longer produces significant productivity gains. Linkage losses outweigh incremental gains, and the system cannot be optimized by middle management.

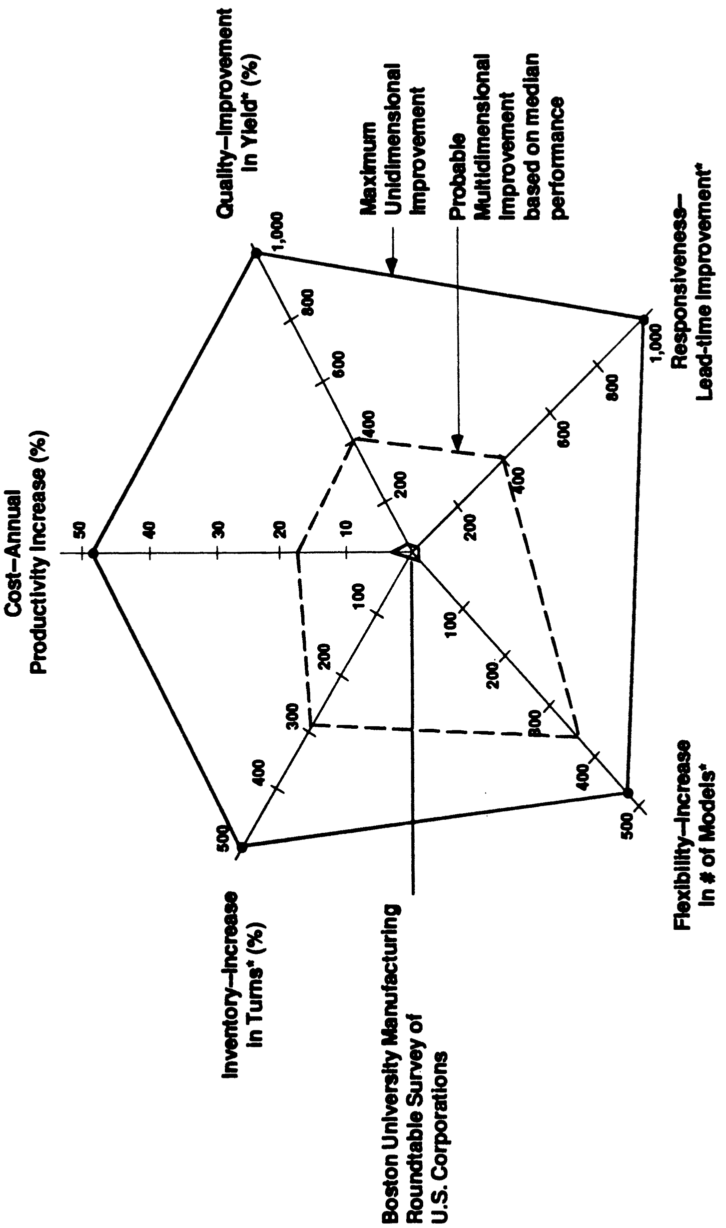
The new paradigm based on accelerating the response of nonlinear dynamic systems has in fact produced predictable results in a wide range of industries, across a variety of systems. In 1989, we conducted a study of nearly 50 business organizations around the world (18 U.S., 16 Japanese, 15 European) which were putting the new paradigm into practice. These organizations had been identified a priori as practitioners from their own statements (for example, Milliken with its total quality and quick response 'religion') or from their competitive actions (for example, Honda). The metrics used were similar to those from Boston University's Manufacturing Roundtable in a survey of U.S. corporations (Miller and Roth, 1988). The Boston University survey showed average annual labor productivity improvement of about three percent, and small changes on other dimensions. Our sample of nonlinear dynamics paradigm organizations indicated an average four-fold decrease in throughput times (measured by order-to-delivery), combined with three- to four-fold *simultaneous* improvements on capital productivity, complexity, and quality over a mean transition period of four years. During this period they experienced labor productivity improvements averaging 16 percent annually, doubling over four years.

The results of our study are shown in Figure 7. The innermost performance shape is the previous Miller and Roth result for U.S. industry. The outermost scaling of the five performance vectors is simply the largest improvement in the sample on that dimension. The time frame for achieving the improvement varied from 3 to 7 years. All companies could identify when they consciously began to change. For example, at Milliken the Quick Response programs came from strategic plans developed with the Crafted With Pride industry trade council in 1984. The sample can be viewed, therefore, as 'progress to date'.

The most significant result is the middle shape. This is the median change in the sample for each dimension. Three non-parametric tests strongly suggest that simultaneous change on all five dimensions is not an artifice of the sample. First, with only four exceptions, all the organizations above the median on one dimension were above on at least three of the four others. Conversely, however, several of the below median organizations did well on one dimension as a result of particular management initiatives emphasized to us during our visits. Second, relative standing does not change more than a few places from dimension to dimension. This is quite surprising given the heterogeneity of the sample; the companies ranged from textiles to steel to autos to glass to electronics to publishing. Third, over 80 percent of the sample bunches within ±15 percent of the median; the distributions along each axis are not only roughly similar, they are fairly tight.

THEORETICAL IMPLICATIONS

The impact of time on productivity in nonlinear dynamic systems is more easily understood in



*Over transition period ranging 3-7 years, averaging 4 years

Figure 7. 50 organizations practicing the new productivity paradigm

simulation models than in a highly complex real world. Pioneering work was done by Jay Forrester in the late 1950s and 1960s (Forrester, 1958). Artificial cyclicality, resonant frequencies, and the smoothing impact of time reduction in nonlinear systems were clearly demonstrated.

There are interesting additional theoretical consequences to the observation that business sytems behave in a nonlinear dynamic fashion. This branch of applied mathematics has become known as chaos theory (Stewart, 1989). The symptomology of chaos should be present and observable. Our own work already provides some findings in this rich area for future research.

- Threshold effects can occur, particularly the onset of turbulence or chaos, at which point a business system can become literally unmanageable. A recent experience showed this in the order-to-delivery process for a heavy truck manufacturer in North America. Much of their product is semi-custom engineered, and average delivery took about 70 days. Management looked at two measures of 'chaos'. First, the number of trucks with problems off the end of the assembly line, something which had proved difficult to reduce despite four years of attention and effort from the chairman down. Second was the degree of schedule delay introduced during the process. A key dynamic driver of the system is the percentage of trucks requiring special engineering (SE) in the incoming order stream. In reality, the demand fluctuates around 50–60% 'standard', and 40–50 percent 'SE'. We developed a nonlinear dynamic model of their system using a simple tool, STELLA, parameterized by estimates from their management team. None of the functions or parameters contain steps or discontinuities; each is a normal, mathematically well behaved description of the various specialized activities from ordering to delivering a truck.

Figure 8 shows the impact on the two performance measures in this model as SE varies from 0.40 to 0.50. In effect, the order to delivery process loses laminar flow and stalls, just like an airplane wing, with the onset of chaos at about 0.45 SE. Since the company's marketplace was operating around the critical threshold, they had inadvertently run a real experiment testing this hypothesis. A special two-month dealer stocking program (only standard trucks) decreased the SE ratio below 0.40. About 45 days after the order ratio changed, the percentage of assembled trucks needing rework declined by more than half. About 60 days after the special program ended, the problem truck percent returned to previous levels. Management became utterly convinced that a new paradigm had to be adopted. By reengineering the entire process, it has made significant strides toward a Board approved goal of reducing the order to delivery cycle to 39 days.

Other elements of chaos theory have also been observed, although these have not been as amenable to clear proof using conventional business performance and accounting measures.

- Sensitive dependence on initial conditions, (the Lorenz butterfly effect) which makes long-term weather forecasts unpredictable. We have been struck by the enormous outcome differences that small changes in initial conditions can make. The evolution of demand under conditions of increasing marginal returns and the emergence of the VHS standard over Betamax is an example of this phenomenon (Arthur, 1990).
- Self similarity. We have been struck by the resemblance of organizational structures, behaviors, problems, and performance at successively smaller or larger scales. Whether organizations, productivity, and quality observe the Feigenbaum constant (Stewart, 1989) is an interesting speculation.
- Strange attractors. Businesses seem to settle into performance patterns which, while never identical, always seem to be within a zone despite changing economics, competition, markets, or management. This would be expected if the company's systems themselves were responsible. Performance would always lie somewhere on the strange attractor, but never repeat, and not be predictable. Major change to break out of the pattern would not necessarily occur if management pursued the specialization paradigm.

STRATEGIC MANAGEMENT IMPLICATIONS

These ideas have significant implications for managers. Clearly, multidimensional three and

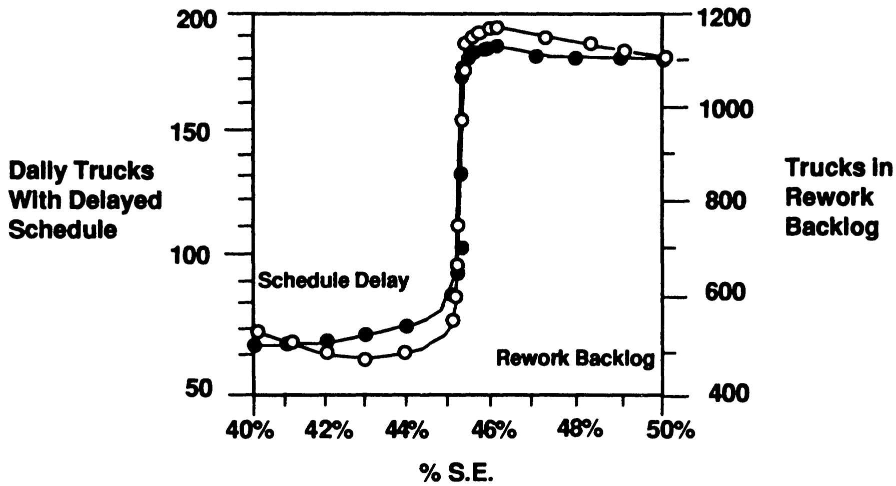


Figure 8. Chaotic threshold effects in a real business system

four fold performance improvements in relatively short time frames become crucial to competitive position. Traditional advantages can be overwhelmed, and not necessarily by the traditional competitors. The best defense may be offense—achieving the capabilities and performance levels implicit in the new paradigm. Ideas for accomplishing this may be transferrable from the mathematical and physical sciences where nonlinear dynamics knowledge is already advancing. This transfer will prove a challenge for economists and managers.

Shedding instinctive approaches

The specialization paradigm is deeply rooted in the way most organizations are conceived. Traditional organizations are specialized hierarchical structures, with departments aggregating into functions, finally culminating in a general manager. Supervision, decisions, and investment authority flow up the solid lines of the hierarchy. Often the specialized departments are the basic budget entity, making them the fundamental unit of productivity measurement, control, and investment.

Most real systems of linked value-adding activity cut horizontally across such an organization. Work moves between the specialized process centers, as in a traditional factory layout, under a presumption of linear sequential flow. The sales organization prospects for an order, which is then priced by marketing, made by manufacturing, and shipped by distribution. Since the actual processes are complex, nonlinear, and dynamic, the organizational structure itself isn't well adapted to minimizing perturbations, or to managing the interfaces.

A recent experience shows how poorly conventional management approaches serve. A Dow Jones 30 company had a cost center of about 65 people located in Missouri reporting functionally through the marketing organization. Its job was to enter order data from North America into the company's computer systems. For years the most senior manager of this department had been subject to productivity pressures, had held employment constant, and cost growth below the rate of inflation. The department was not level loaded. It tried to process the fluctuating order stream as it came in, and naturally was not staffed for the unpredictable peak periods. At peak times people cut short breaks and worked an hour or two of overtime, flexing labor capacity to demand. Fatigue-induced errors in the data entry on 150 possible items with 13-digit part codes had massive multiple effects downstream in the system. Adding two people at a fully loaded cost of $120,000 violated all productivity principles of the specialization paradigm. They were 'excess capacity', only needed at peak times to maintain breaks and regular hours. Yet the reduction in fatigue-induced coding errors saved a production facility in a different state $1.2 million annually in direct labor costs alone! Neither the traditional organizational structure which separated the costs from the benefits, nor the GAAP accounting system which did not trace the systemic cost consequences of data entry error, supported this change.

New management approaches

The consequences of managing complex nonlinear systems are profound, but point in a single direction. At the most basic level, simpler, faster systems minimize chaotic potential. And faster systems automatically improve productivity. Take, for example, sensitive dependence on initial conditions in software development. Small differences, perhaps trivial at the time, can lead to vastly different outcomes under otherwise similar circumstances. This probably makes the eventual outcome of large software development projects the lottery it so often seems to be, and why top down structured programming approaches with imposed modularity help. The simpler, and more nearly linearly independent the subsystems (developmental software modules) behave, the easier the system is to manage.

Two principles borrowed from physical process engineering have proved very helpful in reengineering business systems. First, design in quality and make the systems process capable. Many of the feedback loops causing chaotic behavior are error-correction loops occasioned by less-than-perfect quality. The so called 'hidden cost of quality' and the discovery that 'quality is free' are both systems consequences outside the specialization paradigm.

Second, reduce system reaction times. Some of the architectural principles used to design faster computers seem to work in business organizations. The specialization paradigm calls for a von Neuman architecture. Ford's original assembly line and most organization charts are good illustrations. The time paradigm of nonlinear dynamics calls for a decentralized, parallel processing network, even if each simple process is itself a von Neuman architecture. Co-location of more specialized units of labor (people across an organization chart) or capital (product rather than process centers in a factory) into internally self-organized teams (cybernetic black boxes) tends to reduce distortion and delay as work propagates through a suitably defined system. This is the same design principle behind the dense circuit packaging and parallel processing of Cray supercomputers. A process designed to handle all eventualities (the whole range of orders) is much more complex dynamically than several simple, streamlined processes for different eventualities (for example, classes of orders). This equivalent of RISC rather than CISC computing is true whether in loan processing or in product manufacturing cells.

CONCLUSION

Adam Smith's specialization paradigm needs to be supplemented by the time paradigm of nonlinear systems dynamics for productivity growth to continue. The process of understanding this paradigm in strategic business terms has just begun. At this juncture, we have an empirically and theoretically supported direction. As with all basic paradigm shifts, it will take time to become accepted, and perhaps several generations of 'normal' management science to fully articulate. The impact on competitive advantage makes beginning an urgent priority.

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