

Quantitative techniques in strategic alignment

by P. V. Norden

There is increasing evidence in both the business and technical literature that the operations and strategy processes of many organizations have been aided materially by visualization and modeling techniques. Application of quantitative methods has progressed from relatively well-structured operations to the more speculative aspects of strategy and policy formation. In retrospect, however, the most valuable contribution of modeling has been greater insight: a clearer understanding of the situations and prospects at hand that the mere act of model formulation often provided the planner. This paper illustrates some characteristics of the modeling process, and explores the applicability of quantitative techniques to strategic alignment opportunities, such as current pressures to reduce the "cycle time" of many enterprise functions.

The objective of this paper is to show that the accelerating pace and increasing scope of today's business operations mandate that everyone concerned with strategic alignment planning and implementation—the strategists, planners, managers, and employees—avail themselves of leading-edge tools that could help them run their enterprises with greater success and a better chance of competitive survival. There are tools to identify new opportunities, tools to help comprehend the structure and dynamics of new and existing business and information processes, and tools to assess the consequences of proposed actions.

One of the most important contributions such tools can make is to increase the decision maker's insight into the complexities of the situations at hand, situations labeled by a recent IBM Advanced Business Institute course as "Managing in a Whitewater Environment." The point is that

chaos is here to stay; economic turbulence, competitive buffeting, and precipitous change are the order of the day. Rapid change is our greatest challenge today—both that initiated by ourselves, and that imposed on us by circumstances and unforgiving environments. Those who think we can just "ride out these rapids" and find ourselves in a placid pool where yesterday's policies will bail us out are simply kidding themselves.

We argue that one way to cope with this difficult environment is the appropriate use of quantitative techniques, also known as modeling, embedded in today's management information and decision support systems. This way is consistent with the world view that "you cannot manage what you cannot model." Here, a model is a precise visualization of the situation at hand, which permits manipulation by computer to assess the consequences and relative worth of alternative policies and implementations. The arts of modeling—mathematical, symbolic, graphic, etc.—provide the means for describing and exploring the structures, dynamics, and interactions that make up the situations we wish to understand, control, and improve.

A further plus is that the recent massive improvements in price-performance of computing and telecommunications and progress in deterministic and heuristic modeling techniques permit us to

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tackle what Herbert Simon¹ has dubbed ill-structured (i.e., large and messy) problems we could not handle earlier. We can now go lower in the hierarchy of rigor from the formula to the paradigm, thus to the powerful insight generators of pattern and analogy, and create the newly inter-linked information and business systems we envision.

No claim is made that quantitative techniques are, in and of themselves, a panacea or cure-all for all the ills in organizational ensembles. But it can be shown that they can assist in the crystallization of structured insights. The thinking process that takes place in the course of developing these techniques often in itself affords rapid means for assessing the likely consequences of our actions.

In March 1969 the renowned anthropologist Margaret Mead² had already made this point in *The New York Times*, stating that we are living in times of "change without precedent." This, she said, explains in part why our children do not regard their parents or grandparents with the respect that ancestor-worshipping cultures did in other places and other times. Those cultures, living perhaps for centuries in hardly changing surroundings, could pass on to their children the wisdom of experience and help them cope with most events in their lives. We who did not grow up "street smart" in recent times, intimately confronted with drugs and crime, can hear our children say: "What do *you* know about growing up *today*?" In other words, what can you teach us that we need to know *now*?

The analogy for business is the challenge of managing in times of change without precedent. The modeler will say that this is significantly different from "unprecedented change" by asserting a paradigm shift: The former implies a radical change in functional form describing the events at hand (for instance, going from linear to exponential growth), whereas the latter might merely suggest a change of coefficients (perhaps just the slope of the line depicting growth that was observed all along).

Luftman et al.³ have offered this definition: "The strategic alignment framework . . . reflect[s] the view that business success depends on the linkage of business strategy, information technology [I/T] strategy, organizational infrastructure and pro-

cesses, and I/T infrastructure and processes. . . . The objective is to build an organizational structure and set of business processes that reflect the interdependence of enterprise strategy and information technology capabilities."

In this context, then, the task to model the anatomy and dynamics of strategic alignment encompasses the following:

- Representation of the business planning and operations processes
- Articulation of the characteristics, attributes, strengths, weaknesses, constraints, inhibitors, leverages, and opportunities of constituent enterprise functions
- Tradeoffs of make or buy, centralization or decentralization, tight or loose coupling of functions
- A framework ranging from local to global, in-house to outsourced, niche to business partnerships and alliances
- The roles of size, scale, variety, stability, fluidity, and time

The interrelationships of such constituent ingredients of enterprise add to, in crystallized and powerfully manipulable form, what has been termed the "intellectual capital" of the business. For example, "what-if" simulation of food acquisition, storage, preparation, and dispensing has positioned such giants as McDonald's Corp. and Burger King Corporation among the leaders in their industry. Once such models are developed and are on line, the knowledge they represent can be extended to include current characteristics of the industry, customers, and suppliers, and shared across the entire organization whenever and wherever needed (nowadays globally), providing a basis for real-time decision support.

For the nontechnical reader, we briefly present a few illustrations of modeling and "paradigm thinking." These illustrations are followed, for the applications-oriented analyst, by some examples thought to be of relevance to the implementation of strategic alignment.

Some characteristics of modeling

The approach of today's modeler is to abstract from the observed or envisioned situation at hand those elements, linkages, and interactions that can skeletally describe the behavior of the whole

without losing or masking important effects. In the business or enterprise areas, the management science and operations research communities have often utilized the formal methodologies of the sciences, such as using mathematics to identify key parameters and their relationships. Science confines its attention to phenomena that can be measured, relationships that can be represented quantitatively, causal chains whose internal consistency can be logically verified, and conclusions that can be tested experimentally. An example is Einstein's famous insight into the relationship of energy, mass, and the speed of light expressed in his renowned formula $E = mc^2$. Business decision-making problems rarely meet these preconditions of scientific analysis but are being approximated asymptotically via simulation and heuristic modeling approaches discussed below. Morse and Kimball⁴ defined operations research as "a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations under their control." John Little of the Massachusetts Institute of Technology added to this in 1990 when he said "presentation of analytic results should give the *news* in the data: What does it *mean*? What do I *do* with it?"

Little⁵ also conveyed this delightful difference between a scientist and a manager, attributed to R. C. Mathes, an expert in probability theory: A manager is a person who thinks there exist only two probabilities, 0 and 1; if indeed he or she ever thinks. But a scientist acts as though there exists every probability *except* 0 and 1; if indeed he or she ever acts. Amusing or not, this anecdote is another typical example of how a modeler's mind works. Little further proposed a "decision calculus," a computer simulatable construct couched in the manager's own terms, and states a set of important criteria for judging the merit of such a calculus: simplicity, robustness, ease of control, adaptability, completeness on important issues, and ease of communication with the model.

One of the pioneers of early corporate operations research, Melvin Hurni,⁶ observed as long ago as 1955 that "one of the truly significant trends in business today is the increasing tendency toward introspection with respect to the business processes themselves. More efforts are being made to examine the data coming out of the business process for underlying principles, patterns of regularity, and relationships of an observed effect to

its probable causes, which can be used in the design of more efficient processes and organizations." Note that in those days the primary focus of the modeler was still efficiency rather than new opportunity.

The modeler, as staff to an executive of a company, then has the task to

- Ask the right questions
- Recognize the relevant elements
- Identify the significant parameters
- Determine the significant linkages among the selected elements and parameters
- Speculate on the "right size" and "right content" of the problem (bounding: inclusion and exclusion decisions)
- Evaluate the temporal characteristics of the problem (life cycles, durations, stabilities, and discontinuities)

All of these tasks are part of the processes encompassed by what Luftman et al. termed the domain anchor, domain pivot, and impacted domain representations.³

A knowledge representation paradigm

It may be helpful at this point to review a paradigm I developed to relate the substantive content of a domain, the abstract representations of this content, and the hardware and software and delivery systems (often called platforms by the I/T community) by means of which the relevant information is distributed. This paradigm, termed "the modeling theater," is shown in Figure 1.

The lower-right lobe in the figure, target domain knowledge, represents reality and all the know-how we currently possess to cope with our businesses or tasks-at-hand (all we ever wanted to know about running a hospital, a factory, an airline, a stock exchange, etc.). It contains the day-to-day chaos, the good news, and the bad news. Clearly, at any one time and for any particular problem set we will carve out only a small part of the universe of facts, factors, and figures relating to the problem that we wish to model. But it should be emphasized that this lobe of the paradigm, lobe 1, represents the current limits of our knowledge in the operational domain of interest, i.e., all we know, and all we do *not* know. We should also never forget that the fundamental limitations of the usefulness of any modeling of a

real-world domain are the limits of what we *really know* about the phenomena with which we are concerned.

The top lobe in Figure 1, lobe 2, addresses the means we can use to represent the knowledge of the real domain. The sections that follow highlight the characteristics of a few of these means. They include mathematical equations, statistical formulae, analytic techniques, paradigms, graphs, and heuristics and their implicit and explicit reasoning schemata. Abstracting and representing the domain knowledge in models, application programs, databases, spreadsheets, and expert systems, etc., involves a process termed KE (for knowledge elicitation), which is a combination of teasing the important elements from the domain experts and representing their structures, attributes, dynamics, logic, and linkages in retrievable and manipulable form.

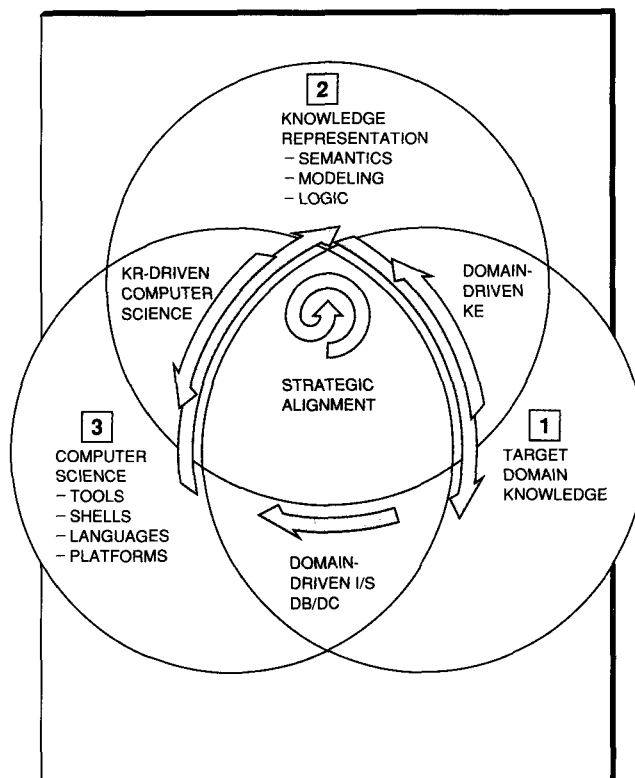
The lower-left lobe, lobe 3, represents the delivery platforms, hardware, software, communication networks, graphics, visualization capabilities, operating systems, expert systems shells, preprogrammed applications, screen-management aids, and (most importantly) the computer languages from Binary to C, by means of which the domain knowledge abstracted by the representation schemata of lobe 2 can be reduced to practice and physically packaged, distributed, and made accessible. Research and development in this area is largely the domain of computer science and the computer industry.

As an illustration, consider the anatomy of what the literature has called decision support systems. These systems, generally, can be viewed as consisting of three elements:

1. A data capture-and-retrieval component for the collection, storage, and retrieval of the information needed for the decisions to be made
2. A modeling-and-interpretation component to manipulate the data, transform information into intelligence, and assess consequences of alternative policies and actions
3. A crystallize-and-display component to display and visualize the results of the above graphically, and distribute them to all concerned

In this case, elements 1 and 3 above belong to lobe 3 of Figure 1; the modeling component again

Figure 1 The modeling theater



spans the problem domain and its KR, or knowledge representation. A large number of problem situations involving decisions, particularly in business and manufacturing, cannot be modeled accurately using physical or mathematical techniques because they are too dynamic or too complex. These problems are best represented in descriptive form, expressed as word pictures of the complex relationships involved in the system. The descriptions, which sometimes must cover the interactions of hundreds of factors, their attributes, and the limitations on performance, can then be considered as a model of the problem. Its components and behavior can be studied for various conditions using simulation and expert systems techniques. The paradigm in its entirety, especially when particularized by a business and its I/T establishment for their own domains, styles of KR, and choice of platforms, is a good mapping of the intellectual property of that business in a specific strategic alignment situation.

Two more observations on the modeling theater: First, before the tremendous increase in cheap

and convenient computing power previously mentioned occurred, only lobes 1 and 3 were used extensively. That era was the time of conventional computing when knowledge was computerized directly from real-world operations into the then-available hardware and software. The deliverables were (and are) applications and facilities from payroll, through text-processing, databases, reports and listings, to advanced data communication and network management protocols. The sophisticated upper path via lobe 2 is relatively new in practice (except for advanced-technology communities such as universities, research organizations, and pioneering innovators). But what this modeling and insight-producing capability has enabled is the reverse flow shown on the diagram: Innovations in hardware and software capabilities as well as sophistication in modeling and visualization have begun to stimulate new insights into the domains-proper. We are beginning a new era of understanding our operations and the higher-order consequences of changes. In short, modeling is instrumental in making explicit *how* we know *what* we know. Specifically, the modeler differentiates problem *substance* from problem *structure* and problem *content* from problem *form*. In the present context, models of both the business and I/T processes can be helpful in exploiting opportunities in linking them, and in making the whole *different* from the sum of the parts.

Second, a key message of the paradigm of Figure 1 is to highlight the scope and focus of each of the three lobes. The popular, and at times even the scholarly, literature often credits improvements in one area to another. For example, linkability or other enhancements of spreadsheets, more pixels or 256 more hues on a color monitor, or a better text editor do not by themselves make the user a better financial executive, architect, or novelist. One is reminded of the old question: If you needed surgery, would you rather be operated on by a surgeon with a butcher knife, or a butcher with a scalpel? Of course, the best of all worlds is a surgeon with a scalpel; in strategic alignment, the corollary is a competent (and visionary) business executive, an equally competent chief information officer, and a world-class modeling toolkit.

Evolution of useful models

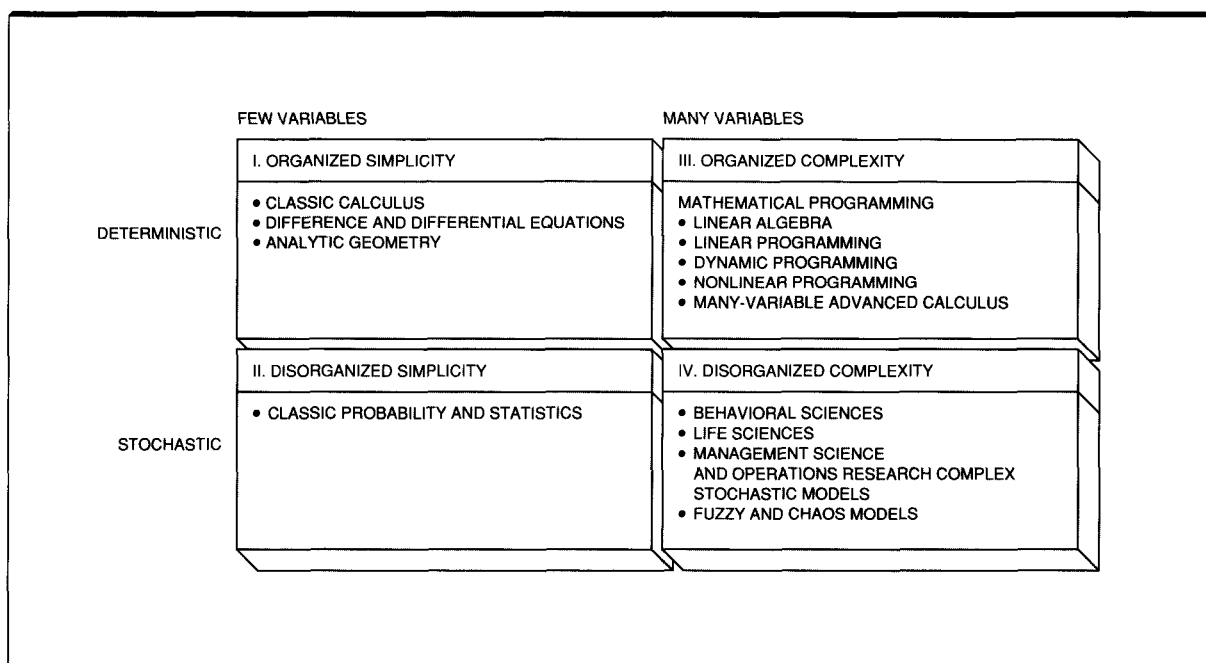
How did the modeling toolkit evolve? The basic so-called primitives of quantification are count-

ing, classifying, connecting, and comparing. With these building blocks one should be able to construct most taxonomies, algorithms, flowcharts

Basic primitives of quantification are counting, classifying, connecting, and comparing.

and computational routines, and perform such tasks as measuring, labeling, rank-ordering, and sequencing. The early operations research/management science (OR/MS) practitioners began with these building blocks and constructed classes of models described as deterministic, i.e., they dealt with variables that took on precise and definite values (as contrasted with ranges or approximations). The world not being all that neat and tractable, they added models that could deal with greater behavioral complexity, described as stochastic (concerned with statistics and probability) and discontinuous (concerned with functions that did not change smoothly and without peaks, breaks, or ripples somewhere in their domain of definition). Going even further in the direction of ill-structured behavior, they are beginning to invoke models using fuzzy sets (initiated by Lotfi Zadeh and his followers who built an entire calculus on the relaxation of the classic set theory, which postulated that the probability of an element belonging to a set must be either 0 or 1; i.e., either you belong to a specified set, or you do not). Fuzzy set theory can handle problems like directing "all the tall boys in this corner; all the short ones over there." Into which corner would a child who is five feet, seven inches tall be placed, and with what probability? Catastrophe theory models deal with even more complex initial conditions and discontinuities. A related, geometric-formalistic representation of the 1970s and 1980s is IBM mathematician Benoit Mandelbrot's development of fractal geometry,⁷ which, invoking the principle of self-similarity, allows us to describe such totally irregular shapes as clouds, snowflakes, mountains, crystals, turbulent flows, and other jagged or convoluted figures. From these examples we can see that the toolkit has begun to address ever more complicated aspects of reality.

Figure 2 Classification of mathematics curricula



Source: Mathematical Association of America Committee on the Undergraduate Program in Mathematics (January 1964)

In January 1964, the Committee on the Undergraduate Program in Mathematics of the Mathematical Association of America attempted to create a general classification scheme for mathematics curricula in the United States. They came up with the neat two-by-two array shown in Figure 2. The bulleted items in the figure are partly my own and are meant to be illustrative. But the taxonomy of deterministic or stochastic and few variables or many variables is very useful. The committee, I believe, was not precise in stating at what point few became many, but it is probably in the neighborhood of five, where certain polynomial equations cease to be solvable by simple formulae. The challenge of many strategic alignment problems is that they largely reside on the right side of the array.

Ackoff and Rivett⁸ provided an early classification of these eight basic forms of operations research problems and the implication that a model could contain a mixture of them: (1) inventory, (2) allocation, (3) queuing, (4) sequencing, (5) routing, (6) replacement, (7) competition, (8) search, and (9) mixed.

Let us return, now, to the tasks of model construction. In terms of Figure 1 we are concerned primarily with the KE and KR processes for domains of interest. The first task is the bounding of the model: Which factors shall be included, which excluded; and of those included, which shall be explicitly addressed? Further, at what level of scale or detail (sometimes called degree of granularity) shall our model be couched? To illustrate, consider the task of the physicist trying to describe the behavior of a gas in a closed container. The physicist could posit an initial position of every molecule of gas in the space, state the vector of its forces and direction cosines, and invoke the dynamics of Brownian motions. In principle, the resultants of this Herculean task are computable, with today's equipment even feasibly so. But for many practical purposes it is preferable, and certainly easier, to deal with the coarser aggregates of pressure, temperature, and volume familiar to harassed freshman physics students as Boyle's Law. Emanuel Piore, retired Senior Vice President of Research and Engineering at IBM, was once asked what he thought differentiated a No-

bel-prize-level scientist from a good conventional laboratory hand. Without a moment's hesitation he replied, "Good taste in [the] choice of problems." This wisdom applies equally to today's strategic manager who needs all the help obtainable to see the right problem at the right time, and to choose the right tools and the right measures for the right decision maker. The modeler's version of Piore's dictum would be "Exercise good taste in your choice of variables!" In sum, apply what students of modeling are taught as Occam's Razor: "If two or more modeling representations yield a result of equal usefulness, choose the simplest."

Since the 1950s, there has been increased interest in the area of so-called artificial intelligence, particularly in its more pragmatic outgrowths of object-oriented programming and expert systems. It is beyond the scope of this discussion to describe these techniques in detail, except to say that they are enabling the modeler to construct very rich and useful knowledge bases, allowing us to ask highly complex strings of if-then and when-then questions. These systems are excellent surrogates in the early consequence assessment stages to evaluate the relative worth of alternative policies or action plans. They have also proven to be excellent diagnostic tools in such areas, among others, as medicine and machine maintenance and have proven to be excellent advisors in such disparate applications as computer help-desks and insurance or loan approval functions. In the 1970-1983 period, Stanford University, Carnegie-Mellon, Rand Corp., and Stanford Research Institute produced the early prototypes of expert systems in areas such as organic chemistry, medicine, structural analysis, and speech recognition under such pioneering names as DENDRAL, MYCIN/EMYCIN, MOLGEN, OPS 5 of Carnegie-Mellon, Heresay, and Prospector. The software that evolved from these early efforts and is now commercially available from a number of sources expands the modeler's toolkit for ill-structured problems considerably. A technique for inducing knowledge from sample data for expert systems design is described by Ting-Peng Liang.⁹ The "hybrid" approach of mixed techniques is described in a 1991 paper by Daniels and Feelders.¹⁰

Some modeling examples

Example A. One of the key problems facing managers today is "downsizing"—force reduction,

generally followed by restructuring or re-engineering the enterprise. But, at the outset, this is a subset of the generic question of what is the proper, or "right," size for the enterprise that is entrusted to a manager's stewardship. Such choice may be conscious or unconscious, explicit or implicit, freely made or imposed from without. There is little in the literature that addresses this problem cohesively, certainly not exhaustively. Yet the upfront selection of size, sometimes made almost capriciously, becomes a subtle determinant of organization structure, complexity, communication effectiveness or just plain "manageability."

Our intuition in these matters fails us very rapidly. The notion of span of control, determined by the amount of time required to supervise each employee in a traditional hierarchy, does not capture the essence of the question. Stafford Beer's¹¹ notion of requisite variety comes closer. He proposes a "methodology of topological maps" for studying and comparing the attributes and behavior of two or more systems. In our case, these characteristics could be the business function for which we envision world-class opportunities and an appropriate information technology infrastructure. Beer addresses the concepts of variety, invariance, and transformation to create so-called homomorphic mappings to compare their properties. This done, he proceeds to questions of measurement and control and makes this characteristic observation: "Often one hears the optimistic demand: 'give me a *simple* control system; one that cannot go wrong.' The trouble with such 'simple' controls is that they have insufficient variety to cope with variety in the environment. Thus, so far from not going wrong, they cannot go right. Only variety in the control system can deal successfully with variety in the system controlled." His bibliography cites W. R. Ashby and other cyberneticists. In the past, their notions have been hard to implement, but the ability of modern computer systems to handle variety, complexity, adaptability, and fast data streams allows us to revisit these paradigms realistically.

What then is the right size for any arbitrary operation? Do quantitative differences lead to qualitative differences? Just how, with some rigor, is the mom-and-pop store different from the multinational corporation? Examine for a moment the design of an organization of about 150 people. From a communications viewpoint, how does one organize? Observe that the structural repertoire

(since the time of the pharaohs!) is relatively meager: hierarchy, fully connected net of all person-pairs, matrix, and hybrid. Consider the first two. It can be shown that the number of people in a hierarchy, S , an average span of control, r , one person (the chief executive officer) at the top, and, counting him or her, n layers is

$$S = (r^n - 1)/(r - 1) \quad (1)$$

If $n = 4$ and $r = 5$, S will be 156, and there will be 155 communication pairs. The fully connected net can be shown to have C such pairs (the combination of S things taken two-at-a-time), which is

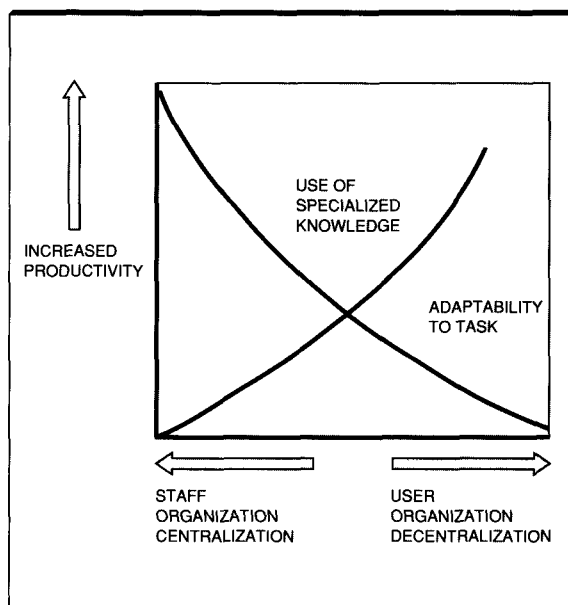
$$S!/2!(S - 2)! \quad (2)$$

In our case, for a 156-person organization, the fully-connected net, allowing every person to talk with every other, works out to 12 090 pairs, fully 78 times as much as the hierarchy. Simon and others have used this as an argument to explain the pervasiveness and robustness of the hierarchical form through the ages. One can easily see that as r and n become larger, even if only slightly, the channel proliferation grows astronomically, even in the more robust hierarchical structure. To illustrate, merely $r = 6$ and $n = 8$ if true "across-the-board," will yield an organization of 335 923 people. This size is exceeded by only a handful of multinational corporations today. And $r = 10$, $n = 10$ yields a company of 1.1 billion employees, a result currently absurd even though 10 people working for one manager and 10 layers of command do not strike us as ridiculous.

If two simple quantified parameters can produce some intuitively nonobvious insights, the argument is made that modeling is worth the manager's time. Here the planner's design considerations are choosing between two at-first-glance contradictory criteria:

1. The number of people reporting to any one manager should be kept to a practicable minimum. (This would call for a "steep" pyramid; $r = \text{small}$.)
2. Communication lines in the company should be kept as short as possible, with as few management positions as possible. (This would call for a "flat" pyramid; $n = \text{small}$, but $r = \text{potentially huge}$.)

Figure 3 Factors influencing organizational productivity



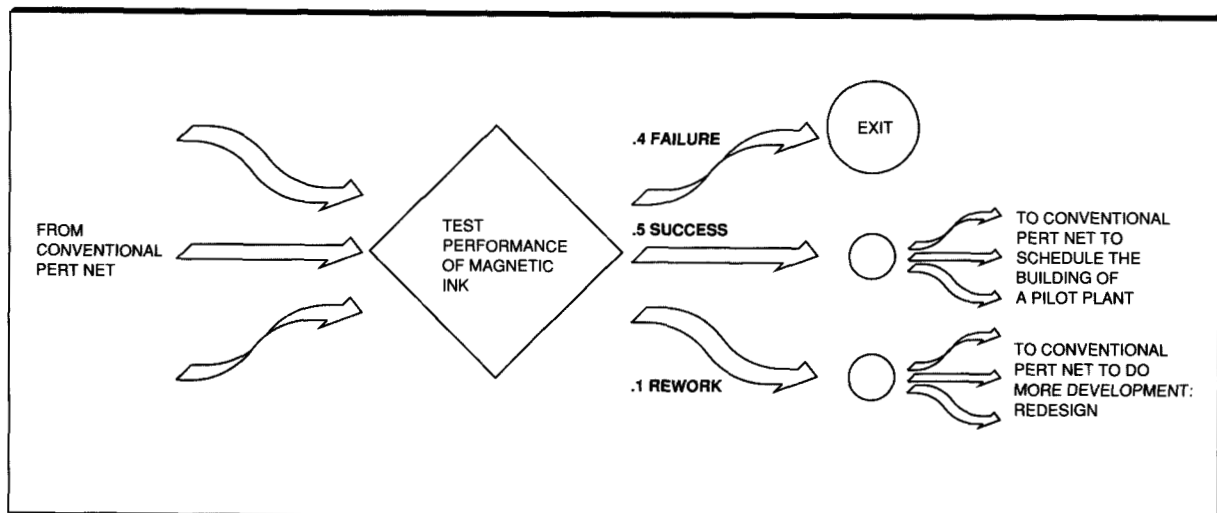
Source: P. Strassman, Vice President, Xerox Corp. (ca 1960)

Real-life answers clearly must lie in hybridity, with the mother organization decomposed into loosely linked and "enabled," i.e., decision-autonomous, subgroupings based on knowledge and mission homogeneities. This is again the "right-size" problem from another vantage point. It is central to strategic alignment implementation using modeling tools to identify problems and possible solutions and simulate the consequences of alternative strategies.

Example B. An insightful paradigm relating organizational productivity to degree of centralization, as a function of the use of specialized knowledge and task-adaptability, is due to Paul Strassman, former I/T Director of Xerox Corp. in the 1960s. (See Figure 3). This problem was re-examined in 1990 via a mathematical/statistical/behavioral analysis by Huber, Miller, and Glick.¹² They provide an interesting over-the-shoulder look at a complex modeling process, verbalizing their criteria of which and how many variables to select for consideration.

Example C. Howard Eisner¹³ developed an interesting elaboration on traditional critical path net-

Figure 4 "Decision box" network detail



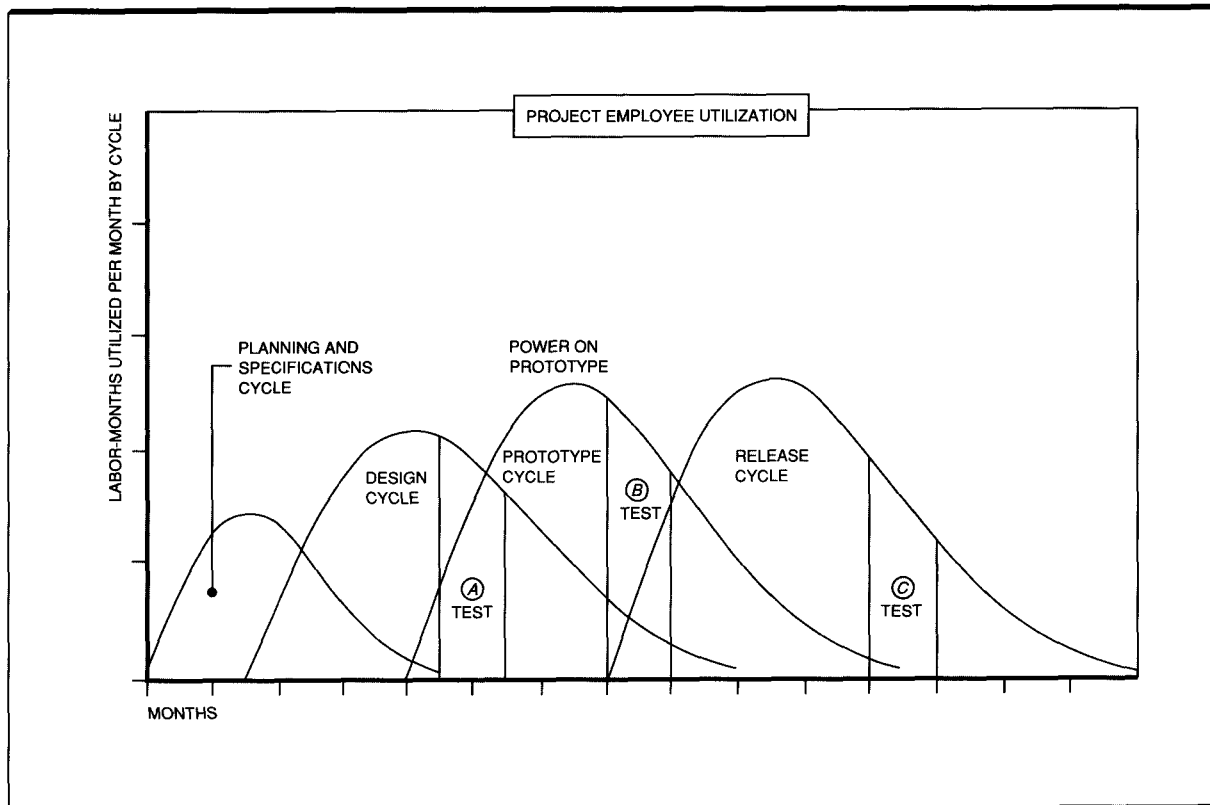
work modeling (Figure 4). Whereas conventional PERT-type networks represent the successor events or activities to any given predecessor event or activity as absolute, unequivocal sequences (implicitly the probability of each arc in such network = 1 in the Zadeh sense previously mentioned), Eisner's networks admit so-called "decision-boxes" and associate a probability value with each arc emanating from such a box. This value represents the likelihood of that particular arc being followed if or when the project reaches the event or activity described by the box. Such decision boxes and probabilistic arcs can be embedded in conventional PERT or critical path nets. The output of such models is, among other things, a table listing all possible outcomes for the project as a whole, the likelihood of reaching each particular outcome, and (if the model has included the necessary numerical data) the time it will take and the total estimated cost to reach each outcome or end event.

Figure 4 illustrates the above conditions for a hypothetical project to develop a new magnetic ink. In this illustration we have reached the point where a pilot batch of the ink can be tested. The *a priori* estimates of the managers and engineer-researchers involved is that at this stage there is a 40 percent chance that the test will fail and the ink be unusable, a 50 percent chance that it will be successful and proceed to pilot plant operation

along a traditional PERT net, and a 10 percent chance that the test will be only partially successful, thus requiring redesign. Note that the sum of the probabilities emanating from any decision box must be 1.0 to be computationally valid, meaning that all possible contingencies have been accounted for and calibrated. For most research and development projects, including strategic alignment planning, this approach provides an additional degree of freedom to represent the inevitable uncertainties of tasks that have never been tried before.

Example D. The problem of estimating the total time (duration) and the total effort (in, say, labor-months) in applied research and development projects has been of interest to managers and analysts for a good number of years. Research that I, and subsequently others, conducted led to algorithms to represent the effort build-up and phase-out in development projects and was called life-cycle method. The background, properties, and use of life-cycle information have been published in a number of places, among them References 14 and 15. For present purposes, to underscore the power of modeling as a source of insight and greater manageability, the focus of the life-cycle model is emphasized. Previously, most research and development project planning, estimating, and control techniques (and, most importantly, the databases to generate and support these ap-

Figure 5 Cycles in the life of a development engineering project



proaches, which were kept as part of the records of the business) concerned themselves solely with two variables: (1) what engineers, researchers, and technicians *did* (e.g., circuit design, drafting, assembly, testing, kept, say, in "department working" records) and (2) what they did it *to* (e.g., tape drives, cables, arithmetic logic units, housings, kept in "product or item charged to" records). It turned out, however, that time series and other models built on these data had relatively poor predictive value. It was only when we noticed that the manpower build-up and phase-out patterns related to *why* the work was being done (i.e., the *purpose* of the effort, such as requirements planning, early design, detail design, prototyping, release to production) that useful patterns began to emerge. The shapes (Figure 5) were related to problem-solving practices of engineering groups and explained by Weibull distributions. Subsequent researchers (notably Colonel L. H. Putnam, originally of the U.S.

Army Computer Systems Command) referred to them as Rayleigh curves, but were dealing with the same phenomenon. The life-cycle equation computes the level-of-effort (labor-hours, labor-months, etc.; the scale is arbitrary) required in the next work period (day, week, month, etc.) as a function of the time elapsed from the start of this particular cycle, the total effort forecast for the cycle, and a scaleless "crashiness" parameter that could represent the urgency of the job. It can be shown that the differential equation derivable from the above is

$$y' = 2at(K - y) \quad (3)$$

where

y' = labor-hours used in current period
 a = a shape parameter, governing the peakedness of one cycle

t = time elapsed since start of current cycle
 K = value of the upper asymptote of cumulative labor-hours (= forecast)
 y = cumulative labor-hours to date

which makes the interesting assertion that the effort required in the next period is directly proportional to the time already spent, to what is left in the budget, and to how urgent the job appears to be! In addition to *a priori* estimating, the most valuable use of life-cycle models has been as an early-warning device to show fast and graphic evidence that "actual" is departing from "plan" and to permit rapid reprojection of what is really to be expected in the way of cost and time-to-complete.

Thus life cycle appears to be a stable and useful entity for forecasting project time and effort requirements. Applicability of the model has been demonstrated in a wide variety of industries from aerospace to banking. An interesting finding emerged a few years after its introduction: Whereas in electromechanical assembled (and other structurally similar) products the total project was multicyclic, software development generally exhibited single-cycle behavior. The latter is probably due to the finer granularity of software development practice, such as CASE (computer-aided software engineering) methods and on-line design, debugging, and systems integration. The hardware model requires stipulation of the lag relationship of successive cycles (i.e., how soon after beginning the planning cycle can detailed design be started?) and their relative magnitude. Historical experience in a company generally allows the creation of a transfer function establishing these two parameters, and then deviations are tracked as the project progresses. Current pressure toward so-called "concurrent engineering" can now be viewed as deeper overlap among successive cycles, notably the ones for design and release to manufacture. It is beyond the scope of this paper to discuss the merits and dangers of too deep an overlap.

Example E. Consider a further model that is a good illustration of the utility of paradigm-turned-algorithm. Once a schedule has been set and a project has begun, it is not uncommon for the project to fall behind schedule. A wag has said "a poorly managed project takes three times as long as anticipated; a carefully managed one only twice as long." Nonetheless, if the project is behind schedule, is it possible to regain the loss? At

what point should it be acknowledged that the project is so far behind that no way exists to meet the schedule? Figure 6 and Reference 16 address this problem. Briefly, we can accept the notion that the earlier it is in the project, i.e., the more lead time is left before a deadline or delivery commitment, the more recovery tactics and strategies we can invoke, and the more slippage time we can make up. If we plot project-time-remaining on the x-axis of a graph, and recoverable-time on the y-axis, we can expect a funnel-shaped function going to zero at or before the deadline date. Research has shown that such a function indeed exists; we have called it the recovery boundary function, or RBF. Its equation is

$$C = ht/k_2(k_1h - t) \quad (4)$$

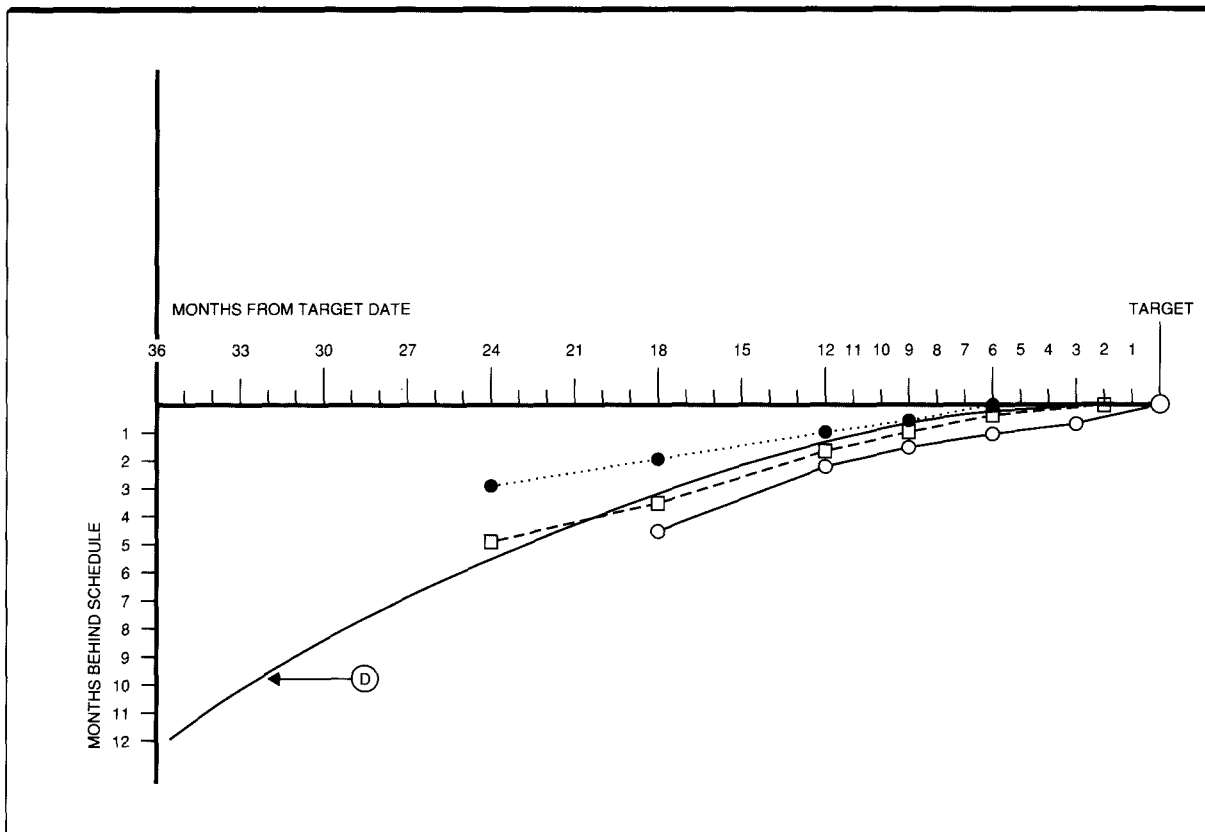
where

C = recoverable anticipated slippage
 h = total expected project duration (original estimate or latest major revision)
 t = time remaining to deadline or target date
 k_1 and k_2 = shape parameters, governing the degree of the size of bell mouth of the function

The function is shown as the solid line D in Figure 6. The other lines are survey results from interviews with project managers of actual hardware development projects conducted in IBM's Poughkeepsie and Kingston, New York, development laboratories in the 1960s.

The RBF implies that project managers behave as though the slippage they can recover is proportional to the product of the original duration estimate and the time remaining, and inversely related to a function of the time already spent. In practice, this model can be maintained as part of the project manager's ongoing control information, and whenever the status-reporting tools being used indicate that slippage has exceeded (fallen outside) the boundary, project review meetings should be called and recovery possibilities (or renegotiation) explored. Plotting the time series of successive actual status points traces the rate at which the project is falling behind or catching up, and can also serve as an early-warning signal. It has been our observation that managers react more to the first deriv-

Figure 6 Two-year project, 75 percent assurance level



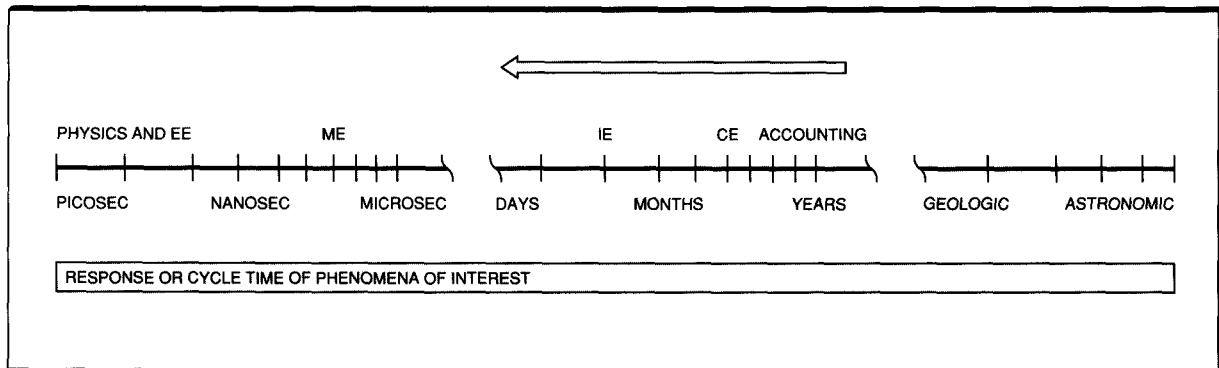
ative of such a time series (i.e., how rapidly they are falling behind) than to the absolute value of slippage at any given time.

Example F. Among the author's present research interests are situation management and time-driven models. The former takes off from the "boundary" factor in modeling, namely, that for any model an early decision is what is to be included and is what is to be excluded in the nascent representation. While classic modeling concentrated heavily on reasonably well-structured phenomena such as queues, or techniques such as optimization, it occurred to me that today's executive is faced with an overflowing in-basket of problems and conundrums with which he or she must deal. I recall that a former U.S. Secretary of Health, Education, and Welfare described his job as "an endless succession of insoluble problems brilliantly disguised as challenging opportunities."

Just as the life cycle proved to be a basic entity of project management, the situation appears to play the same role in general management decision making. A situation is defined as a concatenation of diverse problem elements, boundable in space, time, and domain context. Modeling on a situation basis could be useful in strategic alignment when the interplay of the linkages of strategic business thrusts and I/T characteristics and opportunities must be considered.

Time-driven modeling is concerned with developing a taxonomy of models based on the duration of the dominant transients or transactions of the phenomena being modeled. My interest in this question was originally stimulated by Lotfi Zadeh, mentioned earlier in connection with fuzzy set theory. Zadeh, while at Columbia University, called electrical engineering (EE) "a science of extremely short-lived phenomena." This obser-

Figure 7 Toward a science of short-lived phenomena



vation is a very valuable insight. It immediately suggested to me a spectrum of durations, like a logarithmic scale, on which all phenomena of interest could be positioned. Figure 7 is a crude representation of this notion. At the left end of the scale shown we can place the ever-shortening phenomena of particle physics, the picosecond-nanosecond set. Going to the right, we pass the macro-engineering fields of mechanical engineering (ME), industrial engineering (IE), and chemical engineering (CE) and the domains of accountants, agronomists, and historians. Further to the right we pass the processes of geology and tectonic plates, until at the extreme right we are anchored on the scale of astronomy and cosmology. A question at hand is, are there any regularities or periodicities in model structures or dynamics, independent of the causal systems governing the physical phenomena modeled? A second question is, what use can be made of such a representation?

It is by now almost a platitude to acknowledge that the global competitive race of the 1990s and beyond is based on shortened response cycles combined with high product variety and quality. Prestigious management seminars point out that whereas the old rule of competition was "provide the most value for the least cost," the new one is "do so in the least elapsed time," minimize the cycle time of the entire business, and overwhelm your competitor with speed and variety. In time-driven model terms, this says to move left on the spectrum in Figure 7. But what does this mean in practice?

Here is an example. Consider a situation that required crushed coal to be delivered from a series of trucks to the intake hopper of a blast furnace some distance from the road. Classic labor practice called for dumping the coal onto a pile, loading some carts or wheelbarrows with smaller amounts of it, trundling them to the furnace, and dumping or shoveling the coal into the hopper. Elapsed time is on the order of the manual grasp-transport-release IE processes near the middle of the spectrum. Eventually the operators built a small hill that the trucks could reach and ascend and constructed a shallow chute from the truck to the hopper, sloped so that the coal slid down into the furnace. Elapsed time is computable by hydrodynamic models for turbulent and laminar flow. We have moved toward the left on the spectrum and "stolen" the models residing there to our advantage. By purest coincidence Arnold Reisman,¹⁷ in a totally different context, tells of special cases of Navier-Stokes equations for fluid motions that he developed from scratch to solve an unusual hydrodynamic problem for which he was responsible. It is interesting to add that the next step in the coal example would be to buy the coal in the form of slurry, yielding still faster flow and, frequently, price advantages.

In another case, Ken Fordyce of IBM Kingston and Gary Sullivan of IBM Burlington have, in the course of developing the logistic management system for the Burlington site, concerned themselves with the lead times of different decisions that occur in the manufacturing management process. They have called this aspect "decision tiers" and describe it thus:

Within the complexity of semiconductor manufacturing, four related decision areas, or tiers, can be distinguished based on the time scale of the

There is overlap and interaction between the four decision tiers.

decision window. The first decision tier, *strategic scheduling*, concerns a set of problems that are six months to seven years into the future. Here decisions are made about the impact of changes in the product line, in the types of equipment available, in the manufacturing processes, in the availability of workers, and so forth.

The second tier, *operational scheduling*, considers the next few months to two years. Here decisions are made concerning changes in demand for existing products, the addition or deletion of products, capital purchases, manpower planning, changes in manufacturing processes, and so forth.

The third tier, *tactical scheduling*, deals with problems the company faces in the next day to six months. Here decisions are made about scheduling starts into the manufacturing line, estimating delivery dates for orders, deciding on daily going rates, deciding on how much overtime is needed, last-minute capital purchases, operator training, corrections in manufacturing processes, machine dedication, the impact of yield curves, and phasing in the manufacture of new products. Decisions would be made on the daily going rate for different products, allocation of resources among operations, the number of operators to assign, and machine dedication.

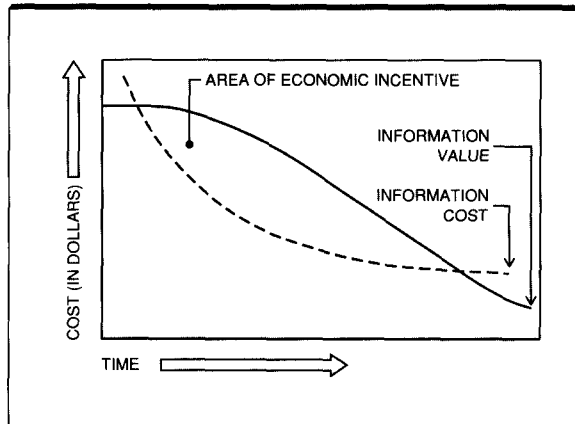
The fourth tier, *dispatch scheduling* or *short interval scheduling* (SIS), addresses the problems of the next hour to a few weeks. Dispatch scheduling decisions concern monitoring and controlling of the actual manufacturing flow or logistics. Here decisions are made concerning tradeoffs between running test lots for a change in an existing product or a new product and running regular manufacturing lots, lot expiration, prioritizing late lots,

positioning preventive maintenance downtime, production of a similar product to reduce setup time, downstream needs, simultaneous requests on the same piece of equipment, preferred machines for yield considerations, assigning personnel to machines, covering for absences, and re-establishing steady production flow after a machine has been down.

Of course, there is overlap and interaction between the four decision tiers; but typically different groups are responsible for different scheduling decisions. For example, maintenance may decide on training for their personnel, work schedules for their people, preventive maintenance, and what machine to repair next. Finance and each building superintendent may make decisions on capital equipment purchases. Industrial engineering may have the final say on total manpower, but a building superintendent may do the day-to-day scheduling. Marketing may decide when orders for products can be filled and what schedule commitments to make. For strategic and operational decisions, these groups and their associated decision support tools are loosely coordinated or coupled. Finance only requires an estimate of required new tools from each building to estimate capital purchase. Each building requires an estimate on new tool requirements from the product development people. For dispatch decisions, they must be tightly coupled. Lots are processed only when the appropriate tool, operator, and raw material are available. At dispatch, rough estimates are no longer sufficient. If a machine is down, maintenance must have the appropriately trained individual available to repair the machine. Manufacturing must have the appropriate mix of tools and workers to produce finished goods on a timely basis. At dispatch, the decisions made by various groups must be in sync or nothing is produced. A manufacturing facility accommodates this tight coupling in only one of two ways: slack (extra tooling and manpower, long lead times, limited product variation, excess inventory and people, differential quality, brand loyalty, and so forth) or strong information systems to make effective decisions.

Further research and experimentation would be necessary to determine how our understanding of the lead-time differentiation of the decisions residing on the several tiers can contribute to more effective execution of the interlinked operations to which they pertain.

Figure 8 Response time and time value of information



Source: Hodge and Hodgson, *Management and the Computer in Information and Control Systems*¹⁸

Example G. Taking a bit of our own medicine, let us consider two paradigms, one due to Hodge and Hodgson,¹⁸ shown in Figure 8; the other by Robert Weinberg,¹⁹ shown in Figure 9. Hodge and Hodgson give us an interesting quantification of the value of information as a function of the response time of the information system that delivers it. Most of us would readily agree that information that reaches us too late to act or compete effectively is of little value. But in the age of FRO (fast response organizations), few people would complain that information can be spewed at us too fast; it might be faster, perhaps, than we can digest or use properly. The paradigm of Figure 8 posits time-dependent functions for the cost as well as the value of information (understood to pertain to a situation at hand), and asserts that there is a range of response-rates that is economically attractive—neither too fast nor too slow.

Example H. Weinberg's classic paradigm in Figure 9 relates the value of information to a sequence of behavioral or inertial lags found in organizations. The heavy top line may be read as, say, the cumulative sales revenue curve forecast for some product for the upcoming calendar year. The bottom solid line is the actual cumulative sales performance; it shows dismal shortfalls due, perhaps, to a combination of ineptness and recession. The following sequence of events then takes place: There is a perception lag until the organization finally officially acknowledges (takes cogni-

zance) that things are not as they should be. Next is an evaluation lag, during which inquiries are made as to *why* things are not going as hoped or forecast. Ultimately some explanation is accepted as plausible by the powers that be, and a decision is made to take remedial actions (price changes, sales drives, etc.). This is followed by an action lag to get the remedial plan approved, funded, and put in place. In the meantime, the graph indicates that performance under present conditions is deteriorating. Finally, the remedy is implemented, and, subject only to the natural inertias of the organization and its marketplace, sales turn upward and close the year at the point where the lower (actual) solid line terminates at year-end. The distance between the planned or forecast point and this last point is the shortfall cost of the present system.

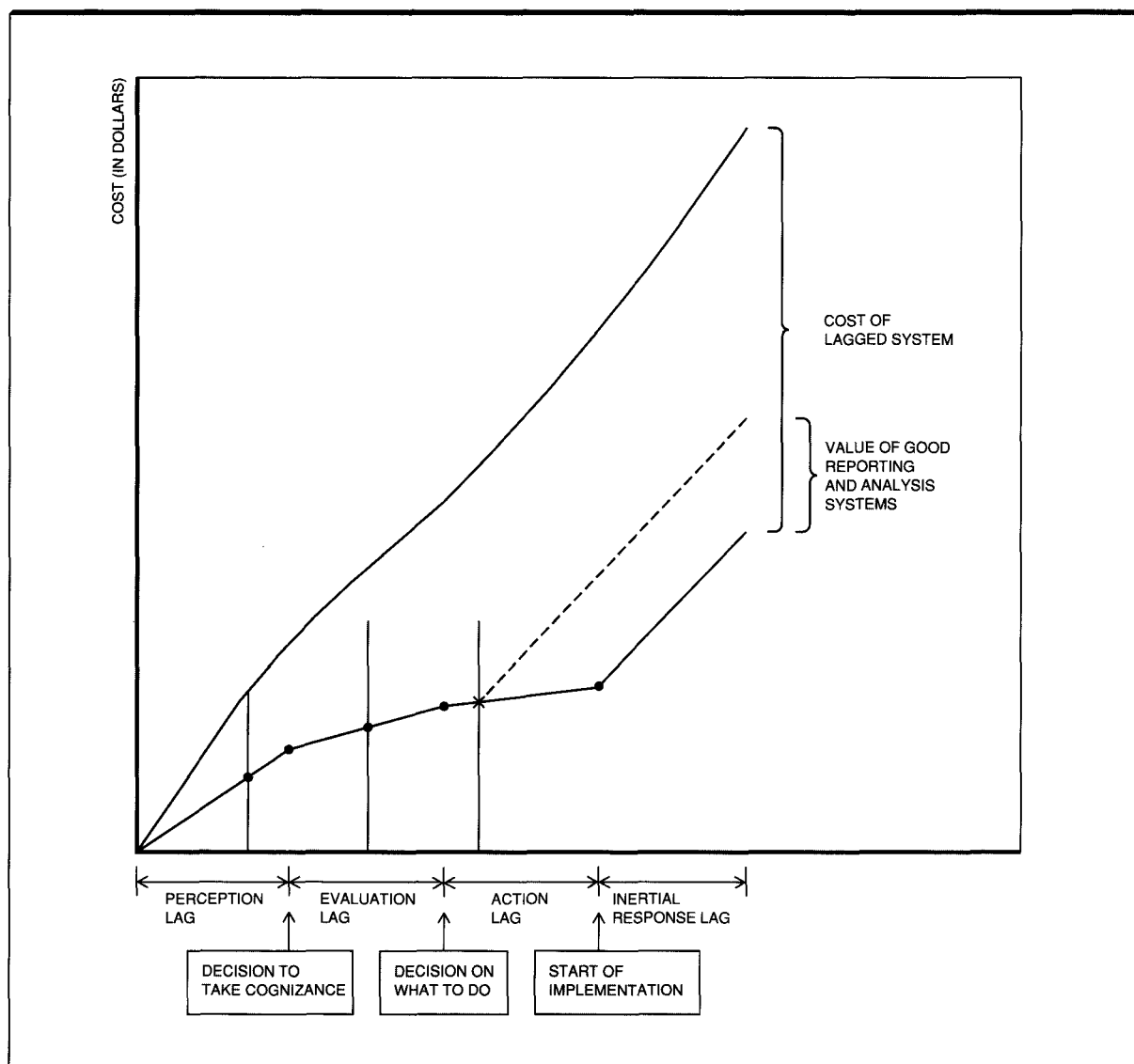
Weinberg now makes the point that if a superior information system and good analytic modeling and diagnosis can shorten the perception and evaluation lags by even a few percentage points (the bureaucracy and inertial lags being held unchanged for purposes of illustration here), the year-end sales results would be at the point where the dashed line terminates, and the distance between this point and the previously described actual point is a fair measure of the value of a good information and analysis system.

Conclusion

In summation, we have tried to show that processes of modeling (abstraction, factor selection, phenomenon-bounding, knowledge representation, model manipulation and consequence assessment) are superb amplifiers of the manager's planning and implementation abilities. They provide insights that are often nonobvious or counter-intuitive and thus highlight both dangers and opportunities that would otherwise have been overlooked. Improvements both in the sophistication of modeling and the price-performance of computing have created a time-of-ripeness that makes operational use of models in planning and implementation truly worthwhile. Here we try to make two final observations: Enumerate demonstrable benefits of problem solutions, and caution the reader against blind use of excessively complicated models.

What is a problem solution worth to an executive? Miller and Starr²⁰ asked this question as early as 1964 and cited seven points that are excerpted here:

Figure 9 Value of timely information



Source: R. S. Weinberg¹⁹

1. The executive may profit from the mere fact of a search for a solution even if no solution is found.
2. The executive may profit from a search that does not find a solution by discovering that some factor that was considered important is not so important.
3. The executive may profit because the range of possible states of nature is narrowed.
4. The executive may profit because the number

of strategies that he or she needs to consider is decreased.

5. The executive may profit by discovering a more suitable measure of effectiveness.
6. The executive may profit by obtaining good estimates of the probabilities of the states of nature (e.g., with which he or she must cope).
7. The executive may profit by discovering the correct evaluation of the payoff measure.

All of these points are enhanced by insights gained from appropriate modeling. Although this exposition clearly has championed the use of quantitative techniques, a word of moderation is in order in closing. This was articulated eloquently by Richard Cyert,²¹ excerpted in part here: "As a model becomes more complicated, however, it becomes more difficult to determine which variables have significant effects on the model's behavior. In other words, the model may become almost as complex as the real world, and, therefore, the model may become almost as difficult to understand (although at least it may be experimentally manipulated and intensively observed in a way which is usually not possible with the real world) . . . We thus find ourselves in a dilemma. The power of computer simulation technique stimulates the formulation of very complex models, but models which are too complex defeat the purpose of model construction, which is to simplify the world so that it can be understood. We caution the users of computer models, therefore, to try to find the middle ground where the model is complicated enough to deal with reality but not so complicated that it impedes our comprehension of this reality." The present author's predilection for gradual complicating of model structures, a paradigm-before-algorithm or walk-before-you-run strategy, concurs with Cyert's dictum. Such an approach is also consistent with Occam's Razor.

A few years ago, the Columbia University Seminar on Organization and Management addressed the theme of complexity in management. During the question-and-answer period, one speaker, a practicing manager, made a statement to this effect: "Complexity is not just a matter of scale or variety. I often have to contend with many factors and many factions. If I can merely guess at the possible outcomes and their likelihood of occurrence, I will call that situation *complicated*. If I can't even do *that*, I'll call it *complex*."

This is an elegant insight, analogous to the electrical engineer's classic "black box" paradigm. In strategic alignment we are dealing with not just one but at least two extremely complex processes. The results of their concatenation are apt to be combinatorially huge. Application of quantitative techniques and modeling can often help to reduce the complexities, make the processes more manageable, and at times unearth intuitively nonobvious opportunities.

Cited references

1. H. A. Simon, *The Sciences of the Artificial*, The M.I.T. Press, Cambridge, MA (1969).
2. M. Mead, *Culture and Commitment*, Natural History Press, Doubleday & Co., New York (1970).
3. J. N. Luftman, P. R. Lewis, and S. H. Oldach, "Transforming the Enterprise: The Alignment of Business and Information Technology Strategies," *IBM Systems Journal* 32, No. 1, 198-221 (1993, this issue).
4. P. M. Morse and G. E. Kimball, *Methods of Operations Research*, Technology Press of M.I.T. and John Wiley & Sons, Inc., New York (1951).
5. J. D. C. Little, "Models and Managers: The Concept of a Decision Calculus," *Management Science* 16, No. 8 (April 1970).
6. M. L. Hurni, "Decision Making in the Age of Automation," *Harvard Business Review* 33, No. 5 (September-October 1955).
7. B. Mandelbrot, *The Fractal Geometry of Nature*, W. H. Freeman, San Francisco, CA (1982).
8. R. L. Ackoff and P. Rivett, *A Manager's Guide to Operations Research*, John Wiley & Sons, Inc., New York (1963).
9. T.-P. Liang, "A Composite Approach to Inducing Knowledge for Expert Systems Design," *Management Science* 38, No. 1, 1-17 (January 1992).
10. H. A. M. Daniels and A. J. Feelders, "Combining Qualitative and Quantitative Methods for Model-Based Diagnosis of Firms," in *Decision Support Systems and Qualitative Reasoning*, M. G. Singh and L. Travé-Massuyés, Editors, Elsevier Science Publishers B.V. (North-Holland), New York (1991).
11. S. Beer, "The Viable System Model: Its Provenance, Development, Methodology, and Pathology," *Journal of the Operational Research Society* 35, No. 1, 7-25 (1984).
12. G. P. Huber, C. C. Miller, and W. H. Glick, "Developing More Encompassing Theories About Organizations: The Centralization-Effectiveness Relationship as an Example," *Organization Science* 1, No. 1, 11-40 (1990).
13. H. Eisner, "A Generalized Network Approach to the Planning and Scheduling of a Research Project," *Operations Research* 10, No. 1, 115-125 (1962).
14. P. V. Norden, "Project Life-Cycle Modeling: Background and Applications of the Life-Cycle Curves," in *Proceedings of the Chinese-U.S. Symposium on Systems Analysis*, P. Gray and Y.-Z. Liu, Editors, John Wiley & Sons, Inc., New York (1983), pp. 101-122.
15. P. V. Norden, "Useful Tools for Project Management," *Management of Production*, M. K. Starr, Editor, Penguin Books, Ltd. (1969).
16. P. V. Norden, "Some Properties of Project Schedule Recovery Limits," in *Research Program Effectiveness*, M. C. Yovits, D. M. Gilford, R. H. Wilcox, E. Stavely, and H. D. Lerner, Editors, Gordon and Breach Science Publishers, New York (1966), pp. 287-318.
17. A. Reisman, "Some Thoughts for Model Builders in the Management and Social Sciences," *Interfaces* 17, No. 5 (September-October 1987).
18. B. Hodge and R. N. Hodgson, *Management and the Computer in Information and Control Systems*, McGraw-Hill Book Company, New York (1969).
19. R. S. Weinberg, "Management Science and Marketing Strategy," *Marketing and the Computer*, Alderson and Shapiro, Editors, Prentice-Hall, Inc., Englewood Cliffs, NJ (1963).

20. D. W. Miller and M. K. Starr, *Executive Decisions and Operations Research*, Prentice-Hall, Inc., Englewood Cliffs, NJ (1964), pp. 378-379.
21. R. M. Cyert, "A Description and Evaluation of Some Firm Simulations," *Proceedings (of the) IBM Scientific Computing Symposium on Simulation Models and Gaming*, IBM Corporation (1966).

General references

- K. E. Boulding, *The Image*, University of Michigan Press, Ann Arbor, MI (1956).
- I. D. J. Bross, *Design for Decision*, Macmillan Publishing Co., New York (1953).
- C. W. Churchman, *The Systems Approach*, Delacorte Press, New York (1968).
- R. G. Eccles, "The Performance Measurement Manifesto," *Harvard Business Review* 69, No. 1, 131-137 (January-February 1991).
- W. M. Evan, "Indices of the Hierarchical Structure of Industrial Organizations," *Management Science* 9, No. 4, 468-477 (1963).
- M. Hammer, "Reengineering Work: Don't Automate, Obliterate," *Harvard Business Review* 68, No. 4, 104-112 (July-August 1990).
- K. E. Kendall and J. E. Kendall, *Systems Analysis and Design*, Second Edition, Prentice-Hall, Inc., Englewood Cliffs, NJ (1992).
- G. Kozmetsky and P. Kircher, *Electronic Computers and Management Control*, McGraw-Hill Book Company, New York (1956).
- A. Rosenblatt and G. F. Watson, Editors, *Concurrent Engineering*, Special Report of *IEEE Spectrum* (July 1991), pp. 22-37.
- D. N. Spergel and N. G. Turok, "Textures and Cosmic Structure," *Scientific American* 266, No. 3, 52-61 (March 1992).
- C. P. Whaley, "Fuzzy Decision Making," *Interface Age*, 87-91 (November 1979).
- D. J. Wright, "Catastrophe Theory in Management Forecasting and Decision Making," *Journal of the Operational Research Society* 34, No. 10 (1983).

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