Generic Models as a Basis for Computer-Based Case Studies*

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ABSTRACT

For many years, system dynamicists have speculated that most corporate troubles could be explained by a small number (perhaps ten to twenty) of *generic models*, behavior modes, and syndromes (sets of symptoms) they create. Recent advances have renewed interest in creating management education materials, using such generic models to provide a consistent and known environment for active learning, using actual case studies for realism and detail, and using the computer-supported *hypertext* format of user-directed inquiry. A project at MIT integrated these advances in computer-based case studies. This paper precedes systematic development of computer-based cases; it identifies 17 problematic syndromes and behavior modes. They are generic in the sense that they occur commonly in a variety of companies, as a result of common structures and policies. The 17 were identified from published modeling studies, interviews with executives, and unpublished consulting studies. The list of common corporate syndromes will be used in selecting the cases upon which to base the computer-based case studies. The list should also facilitate the problem-identification phase of consulting for individual corporations.

1. INTRODUCTION

1.1. Technologies for management education

Progress in four areas now makes possible an effective, theory-based interactive computer environment for teaching corporate management. The areas are: the case study approach, gaming simulation and the hypertext format on personal computers, and generic dynamic models of common corporate problems.

1.1.1. Case studies. As pioneered by the Harvard Business School, case studies encapsulate issues that confronted real managers in a 20-50 page paper, which students read and analyze, either in writing or in classroom discussion. The weakness of the case study approach is the difficulty of correctly analyzing a complex situation using only verbal discussion, which is seldom based on an adequate theory of what determines outcomes.[1]

1.1.2. Gaming and simulation on PCs. PCs and other computers are widely used to manage details of simulated corporate environments, to create elaborate training exercises whose logistics would not otherwise be practical. The weaknesses of simulation games are in several ways the weaknesses of learning from normal work experience. Often, outcomes often depend on the personalities involved, making generalization difficult. And seldom can people repeat a process until they learn to do it well. And above all, the underlying structure of the simulation—the rules by which the learners interact with the simulated environment—are often poorly-known and indeed deliberately hidden.

1.1.3. Hypertext. The concept of hypertext was invented in the 1960s, to distinguish normal linear text presentation—words in a row, starting at one end of a body of knowledge and working through to the end in a fixed, linear order—from the presentation made possible computers. Hypertext allows movement through information along any path, making side excursions to related subjects, selecting appropriate levels of detail, seeing associated pictures and hearing associated sounds, and backtracking to re-examine material from new perspectives.[2] The hypertext format allows a learner to access related materials—be they maps, musical scores, or just more text—with the same ease as proceeding to the next page of a prepared sequence. The weaknesses of hypertext stem from its generality. It is a medium both difficult to create in, and difficult for users to orient themselves within.

1.1.4. Generic models. Although every corporation has problems with unique aspects, there are types of problematic behavior that occur in many different organizations. Generic models—models without the "brand name" of a particular company—portray the common structure of decision-making and action that creates the common problems. The oldest example is Forrester's "Market Growth" model, which shows how biases against new capital investment can create perpetually low product availability (relative to competitors) that inhibits sales growth.[3,4] The weaknesses of generic models as tools for management education are first, requiring a highly-trained modeler to run the model and interpret its structure and behavior, and second, even with such guidance, substantial difficulties transferring insights from an abstract model to real situations.

The four developments—case studies, hypertext, simulation and gaming, and generic models—complement one another. Case studies supply the anecdotal richness needed by generic models. Generic models supply the repeatability and focus on important lessons needed by gaming-type simulations.[5] Simulations of generic models create alternative outcomes with a rigor not possible for ordinary case study discussions. Hypertext supplies an easy-to-use learning framework so that a learner can access anecdotal case materials, simulation experiments, and model information without prior training sessions and practice.

1.2. The computer-based case study project

The Computer-Based Case Study Project at MIT's Sloan School of Management is combining the four elements described above to create management education materials. Two in-house demonstrations use the Apple Macintosh, based on a fairly generic model that accompanies an existing Harvard Business School case study of People Express Airline.[6] Construction of a prototype computer-based case study is under way.

Daniel Kim used an earlier draft of this paper to scan Harvard Business School case studies for cases with generic systemic problems. From the candidates he identified, the project team chose a case on Sun Microsystems, a maker of high-powered engineering workstation computers.[7,8] The case is set near the end of development of the Sun 3 workstation, whose software is not yet ready for release. The most pressing issue is whether to "throw it over the wall" into production, trading off the difficulties of early release against competitive timing and capture of market share. Analyzing the case with a simulation model allows a realistic computation of benefits to compare with costs. A second issue is whether the problem could have been avoided—at what point could resources have been added to the development effort as insurance against the unforeseen difficulties, and what would the bottom line be? Of particular interest are the nature of those resources, for in the Sun case as in many other product rollouts, there is some suspicion that the resources for product design itself were adequate, but that engineering for manufacturability, and other ancillary development tasks received less than optimal resources. A third area for exploration is pricing strategy for the previous product, the Sun 2 workstation.

Kim has begun creating a simple model for the Sun case representing R&D management, product introduction, and sales in a changing competitive environment. The model will be taught at first with a live instructor operating the model. When the pedagogy is better understood, the case will be translated into Apple HyperCard™ software, for further testing and development.

1.3. A collection of generic problem modes

This paper, then, is source material for identifying generic corporate problems upon which to base computer-based case studies. It identifies a set of frequently occurring syndromes, organized into four themes. Each of the syndromes are expressed in terms of a *problem mode*: a set of basic cause and effect relations, the behavior over time that they cause, and the consequent symptoms.

The problem modes are drawn from several sources: the published system dynamics literature, the general business press, proprietary consulting studies by the author and others, and interviews with both managers and experienced system dynamics modelers. The notes give the publicly-available references for each mode.

The problem modes are not mutually exclusive, for real situations can present themselves as blends and "cross-breeds" between modes. For example, slow growth can be caused by chronic shortage of manufacturing capacity, but also at a deeper level, by lack of the organization's capacity to plan and execute investment. The problem modes are also not collectively exhaustive; there undoubtedly systemic corporate problems that no stretching of the descriptions below can encompass, perhaps as much as 30 percent of cases.

2. THEME: CONSEQUENCES OF GROWTH

As a company grows, the increasing scale of operations can cause difficulties; several of which are identified below as part of a problem mode. Depending on the policies involved, the problem modes can manifest themselves as either chronic malperformance or periodic crises.

2.1. Growing demands on management create crises

A variety of practices (R&D, general management, product introduction, resource acquisition) appropriate to an organization when it is small become gradually less effective as the organization grows. If a company's management is always fighting fires and is too shorthanded to anticipate problems, the cumulative effect of growth is to create enough problems to stop further growth. One description of this condition is the Peter Principle: the company has "grown to its own level of incompetence."

A more constructive description is that growth is being restrained by "organizational capacity." Shortage of organizational capacity can create symptoms in many functions. Perhaps inability to manage multiple distribution channels creates an ineffective sales force and poor customer relations. Perhaps technology becomes more complex over time (and a growing company has more products),the organization of engineering (centralized vs. decentralized), or the way in which supporting technologies are acquired (e.g. everything from clerks to CAD/CAM systems) are ineffective and need to change. Perhaps the informal channels from top management that previously have been the source for new product ideas are no longer prolific enough. Perhaps the same manufacturing management adequate for one plant yields snarled production schedules and product unavailability in multiple plants. Whatever the specifics, the common element is the organization's inability to keep major (i.e. profit-and growth-inhibiting) problems from cropping up.

Organizational capacity can cause another behavior mode as well. If management eventually takes notice when performance suffers, the organization will reorganize and restaff, usually for a traumatic transition. For a time, the problems—whatever the specifics—abate. Growth continues for a few years until the management is again stretched too thin and performance deteriorates. Again, reorganization, restaffing, and general trauma occur "on the comeback trail." So responding to the basic problem only when performance is finally and manifestly suffering will create a series of crises, usually 2-7 year resource allocation cycles. This behavior is so well-recognized that crises have come to be expected and accepted at the "break points" in revenue. Alternatively, some companies explicitly add organizational capacity ahead of time, with considerable apparent success.[9]

2.2. *High growth reduces proportion of experienced employees*

Growing organizations must hire outsiders. Even when new hires are experienced in the same industry, there is a delay, possibly measured in years, before they are as effective in their jobs as are experienced employees. Becoming familiar with a company's products, procedures, and resources takes time, regardless of previous expertise.

Rapidly-growing organizations need for large numbers of new outside hires, which will cause "dilution" of the experienced employees. As the number of employees begins to grow due to hiring of inexperienced employees, the proportion of experienced employees falls. Even though the hirees are assimilated after a time, the ranks of inexperienced employees are replenished by still more hires. The longer it takes to assimilate employees (or the larger the growth rate) the more severe the dilution becomes. The inexperience of the average employee manifests itself in poor performance, whether in the arena of sales, service, engineering, etc.[10] Depending on the specific situation, the poor performance can be a steady brake on growth, or occur in episodes of alternating heavy growth and heavy difficulties.

2.3. *Aging product lines reduce aggregate revenue growth*

Most products follow a life cycle. Following the products introduction, sales revenues rise for some years, as its availability (and often descending price) create an expanding market. After a period of expanding sales, several factors may then reduce sales. Most potential buyers may already have bought the product, so that sales are reduced to just replacement sales. Or perhaps the product is displaced by newer products or even new product categories. Or imitation by competitors may cut into sales. For whatever reason, sales of many products show a rise and then a fall as the years pass. This "life cycle" of revenues from individual products has an important effect on a company's aggregate revenue behavior.

A high rate of product introduction in the early years of a company means that most products at that time are in the "rising revenues" portion of their life cycle. Later on, aggregate revenue growth slows as the individual product revenues slow. Boosting revenue growth in any time less than several years may be extremely difficult if the company has an "aging product line," where most are in the declining revenue phase of their life cycle. Attempts to boost revenue growth quickly in such a situation must fail to redress the long-term problem.

2.4. *Constant growth requires exponential product creation*

Even with a product line balanced between newer and older products, a company may not be able to maintain its growth rate. Maintaining a constant percentage growth of revenues over several years requires one of two things: either a constantly growing rate of product introductions, or constantly increasing life-cycle revenues per product (not just revenues per year which usually rise at first for any product). Failure to have one or the other causes revenue growth to fall short of former performance.

A continually-rising rate of new product introductions may be inconsistent with a niche market strategy—a company cannot grow faster than its niche indefinitely. Goals of constant growth can create a strategic dilemma, for sometimes a company must either accept slower growth within a niche, or cease to be a niche-product company.

3. THEME: RESOURCE BOTTLENECKS

The idea of bottlenecks is well known and accepted in business culture; oddly, the habit of clearing up bottlenecks is not nearly so pervasive. Even though the numerous variations on the bottleneck theme may seem trivial on paper, they are not; many perceptual, analytical, and organizational barriers prevent prompt clearing of bottlenecks.

Note that identifying a resource bottleneck problem does not imply that the proper cure is necessarily just supplying more resources, especially as a one-time correction. Changing resource acquisition policies, staffing policies, corporate organization, compensation policies, internal reporting systems, product pricing, or even acquiring other companies may be the appropriate corrective action.

3.1. Fully-utilized manufacturing capacity limits sales

Probably the most common variation of the resource bottleneck theme is fully-utilized manufacturing capacity.[11] Internally, the manufacturing organization can take pride in very effective use of both plant and finished inventories. Management can take comfort from large (and long) order backlogs, interpreting them as a sign of demand, (rather than unfilled demand). But it takes customers a long time to obtain the product, or normally-available products are sporadically unavailable. For customers, the company's products are not as desirable as they would be if they were more available. Sales therefore take more time to make than they ought. Competitors develop and deliver similar (or even inferior) products, with higher availability as one of the selling points.

The interesting and challenging aspect of resource shortages is not that they limit sales, but the budgeting, forecasting, and standards-setting that underlies the decisions that result in resource shortages. Few managers would deliberately create a sales-limiting resource shortage. Often, capacity shortage is created by setting standards inferior to those of competition, or hiring, training, and investment policies that make sense for constant demand, but not for growing demand. Alternatively, underinvestment can result from underpricing a product. (See "low prices create pandemic resource shortages" below.)

As with any resource bottleneck, the fully-utilized manufacturing capacity problem mode can manifest itself either as an ongoing problem or as periodic crises. If the nature of the resource shortage remains invisible to upper management, the problem will persist continuously and limit growth. If the manufacturing resource shortage is recognized and substantially more capacity is acquired, sales grow, slowly at first and then gathering momentum as product availability and high revenues both improve the business climate. This sets the stage for sales to again overrun capacity and create another sales and growth crisis.

3.2. Fully-utilized sales capacity limits sales

It is very common for firms to have suboptimal numbers of salespeople by factors of two and beyond.[12] But there are no obvious symptoms aside from low aggregate product revenues, for the sales force under such circumstances is quite efficient, perhaps with productivity higher and costs lower than industry averages. To realize how common a problem inadequate sales resources is, recall how many corporate rejuvenation initiatives involve increasing the sales force (often by transfer from other functional areas).[13]

3.3. Customer service capacity limits product saleability

"It's a great product but you can't get service." Small companies often offer low-priced products superior to higher-priced products of major companies. But the low-priced products aren't competitive because the small company has little if any service organization. In another variation, rapid growth in product sales leaves an organization short of customer service talent. (see "High growth reduces proportion of experienced employees" above.)

3.4. Competitiveness lags without process-improving investment

Organizations tend to stand still. The tendency is particularly acute if there are no resources devoted to improvement. One extreme that still often surprises young companies is not putting effort into new product development—the product success is regarded as a "one-shot" affair, after which the company is considered implicitly or explicitly to be well-established. Competition usually puts an end to that belief and often the company as well.

The manifestation typical of larger and mostly successful companies is to treat installation of manufacturing capacity as a "one-shot" affair, and budget very little for process improvements or continuing expansion. Especially if short-term financial results are emphasized, few within the company can afford to advocate spending, say 5 percent of revenues to reduce costs by 3 per cent of revenues per year thereafter. Yet the payback is there, both in terms of cumulative cost reduction and in terms of the expertise developed that applies to many other processes and products. One case in point is the dramatically larger proportion of Japanese engineers devoted to manufacturing process improvement relative to American companies.[14]

Another variant of shortchanging process improvements happens when an organization decides to convert to new production technologies, but then skimps on allocating people and money to prepare for the conversion. The most common cause of failure in implementing new technologies is failure to invest, not in cash, but in people's time.[15]

3.5. R&D capacity limits new product introductions and quality

There is a temptation to initiate as many projects as exist viable markets for (or as many as are technically feasible), regardless of how few development engineers are available. The excessive number of projects per person reduces R&D productivity due to more time for switching from task to task, scheduling complexities, multiple reporting relationships, etc. If the condition endures, low R&D productivity creates more shortfall of product introduction and more pressure to overload.[16]

This is a problem mode where the solution is not only simply to acquire more resources (i.e. R&D people and facilities), but also reorganize to allow each person to be working on an appropriate number of projects. After all, large companies such as IBM and GM manage to carry on R&D nicely, in part by shaping the organization to the tasks at hand.

3.6. Overly ambitious projects overstep R&D or marketing capability

Need for more product introductions and revenues can motivate a variety of responses. One is to increase the technical ambition of initiated products, looking for "blockbuster" advances that can significantly bolster revenue growth. This can give an R&D staff tasks beyond their major areas of technical strength, or even beyond the realm of feasibility for any real organization[17]. So product specification may be ill-advised, and the development will encounter difficulties far beyond the norm. Bottlenecks of technical capability very commonly show up when firms are installing new production technologies (see "Competitiveness lags without process-improving investment" above).

3.7. Low prices create pandemic resource shortages

Another viewpoint on resource shortages comes from looking away from which resources are short, and looking toward *why* they are short. Often, the answer lies in pricing policy. Typically, a company has a hot new product, that it prices to give a very decent margin, but far less than the market will bear. Sales take off, but the company lacks cash to expand. Sales then become limited by product availability or poor-quality service and support (as in the modes described above). So the company sits with excess demand, moderate growth, and cash shortage.

Start-up companies often either sit with moderate growth until a larger competitor introduces a similar product and bankrupts them, or borrow money to expand and get pulled into bankruptcy by (otherwise) minor business reversals.[18]

When price-induced resource shortage occurs in larger companies, the result is often perceived as a widespread malaise, where hardly any functional area is going well, since all are cash-starved. Product development is often hit hardest, so that in a few years the cause of the malaise is incorrectly (or at least narrowly) perceived as poor new product development.

4. THEME: RESOURCE ALLOCATION CYCLES

These problem modes involve a resource allocation policy that reacts to problems only after they've developed ("the squeaky wheel gets the grease"), resulting in "too much, too late" which sets the stage for another crisis down the road, either in whatever areas were deprived of resources in the haste to solve the present problems, or in the same area after complacency and then neglect set in. In principle, any resource bottleneck can be the source of resource allocation cycles.[19] In practice, the problem modes below are especially common, hard to diagnose, and highly damaging.

4.1. Employment, inventories, and order backlogs drive production instability

Sometimes, control of finished inventories becomes an end in itself. Unexpectedly high demand and thus too-low inventories call for production increases. But because it takes time to change production plans, hire production workers and put additional raw materials into the ordering pipeline, production cannot be increased immediately. Inventories sink further during the delay, so when production comes up, it must not only meet the higher demand, but also restock depleted inventories. So production must increase higher than demand, creating an overshoot. Often, companies have swings in employment and production that in percentage terms are larger than the swings in sales.[20]

An equally-prevalent variation on the fluctuations just described occurs in firms that do not hold finished inventories, but do have substantial product order backlogs. In such firms, employment overshoots when a backlog builds up and requires more labor not only to match sales (more precisely, the order placement rate), but to reduce the backlog down to appropriate levels.[21]

A final variation occurs in multiple-stage production-distribution systems. For example, a product might go through the hands of not only the producer, but also a distributor, a wholesaler, and a retailer before reaching the final purchaser. At each stage of the distribution chain, the delays in filling order backlogs or replenishing inventory are not the delay of building up employment, but delays from other stages in the distribution chain.[22]

4.2. Resources cycle between improvement innovation and exploration of new technologies

Products can differ enormously in the profile of profits they create over time. Products that modestly improve on existing products ("derivative products") sell into an established market and the payback is moderate, quick, and certain. Products that represent either an innovative, new application, or use of a new process technology may have larger initial costs, slower and more uncertain revenue growth, and yet much higher eventual revenue potential.

If revenues are needed quickly, resources (engineers, facility time and acquisition) go to the derivative, less innovative products. Eventually, this creates a product line with little growth potential, and a recognized need for more innovative products. A "crash program" results. In the push to pioneer new areas, the older technologies may not even be harvested adequately. The stage is then set for another round of getting the "ground broken" and then swinging back to derivative products. So a cycle goes back and forth between derivative and ground-breaking product development.[23]

4.3. Resources cycle between R&D and manufacturing, and marketing, and customer service

One consequence of a big push to develop new products is that management attention, engineers, and resources all follow the products as they go into production and marketing. That constitutes a significant resource swing away from product development. After a while, the (once) new products enter the lower-growth portion of their life cycle, and there is a suddenly-perceived need to "fill the product pipeline" again. In a year or two, the pipeline is full again, new products go into manufacturing and marketing again, and the stage is set for another cycle. The shift of focus and resources between development and manufacturing/marketing underlies the commonly-observed "waves" and "generations" of product introductions.[24]

5. THEME: MANAGING PRODUCT LIFE CYCLES

The first three themes take a top management viewpoint, analyzing the processes by which resources are controlled among numerous products in all phases of their life cycle. By contrast, the problem modes of this theme describe the development and marketing of a single product or product line.

5.1. Not reckoning total benefits to compare with cost

There are recognizable problems that arise from lack of explicit calculation of the bottom-line benefits of various policy options.

Product development planning often takes little account of the end market. Derivative products may be inexpensive to develop and therefore allocated considerable resources, even though the end-user market for them is shrinking and the revenue potential is therefore relatively small. Inversely, an innovative product can appear expensive and therefore be subjected to resource-skimping (if it is approved at all), even when a modest amount of additional resources would allow shorter time to market and capture of a larger share of an untapped and growing market.

In the absence of comprehensive cost/benefit analysis, new products are often shortchanged on sales effort . In many industries, the cost of having salespeople call on clients periodically is accounted for as a variable cost, a sales expense. But for new products especially, the sales effort is actually an investment with returns over time. Salespeople must call on clients until the clients are ready to buy the product. Purchases then follow in a steady stream, with much less sales effort required—"maintenance." But when a new product is one of many, and in the absence of explicit calculations on the return to marketing investment, the allocation of sales effort it receives is likely to be that appropriate to an established product. Sales revenues for the new product therefore climb more slowly than would have been possible with a higher, more investment-oriented effort allocation.

5.2. Adding capacity in a saturating market

One form of absent benefit calculations happens so often it is identified separately here: the classic trap of market growth, saturation, and decline, where significant resources are consumed by meeting demand from a market which then saturates quickly. The result is often extensive, expensive, and very specialized capacity idled, with negative net profit due to capacity costs.[25] Many innovative products newly-introduced to consumer markets show this behavior, for example with VCRs and chain saws. Several generations of semiconductor technologies likewise followed this life cycle. The problem mode is very well-known; but in the absence of a clear quantitative analysis, the profits and growth apparent in the (short-term) exploding market are often much more compelling than ill-defined and hard to reckon considerations of market saturation.

There is a cyclic version of this problem mode, common in the building industry. Because of the long delays in especially urban construction, the real estate industry cannot respond to need for space. If there is a shortage, it will be several years before it can be corrected, and all during that period, the low vacancy rates and high rents make building very attractive. When new buildings are through the pipeline and ready for occupancy, there are too many. Vacancy rates rise and rents fall, which inhibits further construction. So for several years, little construction takes place and a shortage develops, which sets the stage for another building boom.

5.3. "Over the wall" to production too soon

It can happen that benefits are clear and compelling, and indirect costs are hidden, during the rollout of a hot new product: "Be first to market! (and damn the torpedoes.)". Early release can abridge several processes: modification from marketing considerations (is this really the product people will want?) manufacturing engineering (can we make the product?), qualification testing (does it work, as manufactured?), or also marketing groundwork (what materials and programs are needed to have people sell it?).[26] Early release often causes long "ramp up," where continuing manufacturing difficulties with processes and materials cause high reject rates or changes in specification and parts reordering (with consequent delays). The new product can tie up production facilities even though production falls short of full volume. Redesign post-release costs considerably more, and sales may be hampered by quality problems and lack of fit with customer needs. It is sometimes unclear whether early release hastens or in fact delays a product reaching the market.

The frequency of early production problems may be one motivation for the recent focus on parallel rather than sequential development efforts, where significant efforts on manufacturability and marketability are made in parallel with development of the product itself, rather than afterwards (i.e. in sequence).[27]

6. CONCLUSION: NEXT STEPS

In draft form, this paper has already fulfilled one of its primary purposes, by facilitating the identification of the Sun Microsystems cases as attractive candidates for conversion into a computer-based case. The case addresses (or at least raises the possibility of) the last problem mode-"over the wall too quickly."

The question of How generic the modes on the list? The question is empirical, but difficult. Ultimately, the only way to verify that problem modes are generic is to use the list and measure the extent to which the entries describe real problems. Such uses include constructing computer-based case studies and doing consulting studies based on them. In the interim, the list would benefit from wider input from experienced modelers. Are the modes described here consistent with dynamic problems as professional modelers see them?

There will undoubtedly be new generic corporate problem modes discovered, as system dynamics modeling is applied in more types of enterprise. System dynamics started in manufacturing, distribution, and R and D areas, and not surprisingly, most of the extant generic problem modes lie in these areas. Although good beginnings have been made, several areas remain underexplored: human resources and organizational effectiveness, marketing, and service quality, to name a few. Service industries in general and financial service companies in particular are underexplored.

Finally, the concept of dynamic or systemic problems needs considerable clarification: what defines the problems at which system dynamicists are good at solving? And what distinguishes questions uniquely addressable by dynamic modeling from more traditional MBA fare?

* The research reported here is part of the Project on Systems Thinking and the New Management Style at MIT, with funding from Analog Devices, Incorporated. Special thanks are due to Ray Stata, president of Analog Devices.

1(Kardes 1987) describes the "atheoretical nature of the case method."

2The two primary examples are *Guide* from Owl International (described in Eckhardt 1987) and HyperCard from Apple Computer. There is a long history of experimental and company-specific hypertext systems, summarized in (Conklin 1987).

3(Forrester 1968). See also a more recent and expansive treatment in (Senge 1986), nearly a classroom exercise in (Morecroft 1986) and a more analytical exposition in (Morecroft 1985a).

4In addition to the present research project, (Graham and Scogin 1985) discusses generic models in a variety of fields, along with a progress report on a generic model of the process of bringing a new technology on board. (Paich 1986) explicitly ties fairly generic models to extant case studies.

5Use of explicit, knowable models in gaming-type educational exercises seems to be effective educationally, although definitive studies haven't yet been made. Studies in (Roberts 1979) show that using such exercises (as opposed to standard classroom learning) measurably increases the participants sense of control over the future. Those studies did not contrast the results with any obtained by playing a non-model-based (and thus presumably less scrutable) game, so the role of models in the efficacy of active computer-based learning has yet to be objectively demonstrated.

6The case is (Whitestone 1983). The first demonstrator was created by Jenny Kemeny and Ted Larkin, programmed in True Basic. The second demonstrator was created (and continues to be extended) by Becky Waring, using Apple HyperCard™ software. Peter Senge and John Sterman did the modeling and pedagogy for both. The computer-based version of the case is described in (Senge 1988).

7The current project team consists of the author, Janet Gould, Daniel Kim, Peter Senge, and Rebecca Waring.

8The pre- and post-product release situations at Sun are respectively described by (Langowitz 1987) and (Freeze 1987).

9Two companies with explicit policies for installing extra management capacity to avoid the "break points" are Apollo Computer and Tandem Computer. Extra organizational capacity may be an element in IBM's practices as well. As one ex-president stated, "IBM never reorganizes without sound business reasons. If we haven't reorganized in a couple of years, that's a sound business reason."

10The demonstration case study on People Airlines is an example of this problem mode. Other examples are Wang Laboratories in the early 1980s and Prime Computer in the late 1970s, when rapid growth caused rapid hiring of service and support people. With so many inexperienced employees, the quality of service fell, and when customers realized it, so did the growth rate. The Prime Computer experience is described in a Harvard Business School case study, (Buzzell 1984).

[11] As mentioned above, Forrester's "Market Growth as Influenced by Capital Investment" is the classic treatment of this problem mode. (Morecroft 1983) on product lines sharing common production capacity is one important variation.

[12] Morecroft's studies of salesforce planning during product transitions (Morecroft 1985b) and (Morecroft 1984) are the major published work.

[13] In the "computer crunch" of 1984-1986, both Digital Equipment Corporation and IBM expanded sales staff, although DEC expansion was primarily through hiring and IBM's by internal transfer.

[14] (Weiss 1984) examines electric goods manufacturers in Japan and the United States. He finds that Japanese companies *do not* have lower absenteeism, lower turnover, or work harder than their U.S. counterparts. One of the major differences he found was the much larger proportion of engineers assigned to the factory for process improvement. Other differences were more selective hiring, steeper wage response to both seniority and demonstrated ability, and lower interest rates for Japanese companies.

[15] (Graham and Scogin 1985) review the literature on success and failure in implementing new technologies. The primary modes of failure, all of them related to shortage of resources, especially people's time, are: 1) Involving the eventual users of the new technology too late in the specification / implementation process. People are both unfamiliar and thus antipathetic to the new technology. 2) Chronic shortage of formal and informal learning opportunities. Without management support of continually upgrading skills, forgetting and attrition erode skills, and effectiveness of the new technology suffers in operation. 3) Expert shortage. Unwillingness either to pay for external expertise like consultants and trainers, or to support development of experts internally leaves the organization less able to cope with unusual circumstances, particularly breakdowns or maladjustments of complex equipment.

[16] (Richardson 1982) is the classic work on overambitious R&D project initiation.

[17] Three examples of failed "blockbusters:" 1) ITT's efforts to adapt its central telephone switching equipment for the European market, System 12, to the U.S. market. Not only technologically daunting, the project was also plagued by management split between the U.S. and Europe. The attempt was ultimately abandoned. 2) GM's "Saturn" project for recapturing market share in low-cost cars through advanced technology. The Saturn car has yet to appear, its targeted market is gradual shifting to the mid-price range, and GM managers are now speaking of simply using the technologies in existing car lines, rather than creating a separate car company. 3) Apple's Lisa computer was successfully developed, except that Apple had entered the completely unexplored territory of expensive, high-performance *executive* workstations. This 1983 product was introduced about when Lotus 1-2-3 was; at that time the only high-powered single-user computers were engineering workstations. However, the technology developed in the Lisa went through another round of refinement and was used in the highly successful Macintosh computer line.

[18]Osborne Computer is perhaps a case in point. Its products dominated the portable computer market and were a significant presence in the nonportable office computer market as well. The sales and marketing staff and development staff both expanded dramatically. Then the company announced a significantly improved model. Customers waited for the new model, and cut back purchases of the older model. That interruption in sales was enough to cause bankruptcy, despite the history of growth and profitability.

[19]To be more precise, fluctuations can arise from any resource that is controlled by a feedback loop with another stock or level (perhaps a delay), with some conditions on the gains and delays involved. See (Graham 1977) for general discussion on oscillations.

[20]The classic study of cycles created within a firm (and between the firm and its customers) is the Sprague Electric case, which was the first major system dynamics study. It is described in (Fey 1962) and (Carlson 1964). A version of the model appears in (Forrester 1961). Another case is described briefly in (Schlager 1964).

[21]A very complete description of the employment-backlog fluctuations of a high-quality machine parts company appears in (Roberts 1978a). Aggregate models of economic sectors including both inventories and backlogs likewise show fluctuations that are thought to underlie the 3- to 7-year business cycle. See e.g. (Mass 1975).

[22]One of the two major models in (Forrester 1961) represents a production-distribution system. In general, production-inventory-backlog cycles do not occur in isolation; additional structures amplify the tendency to oscillate. Other stages of a multi-tier distribution system are but one type of such structures.

[23](Weil, Bergan, and Roberts 1978 describe describes such fluctuation as "workflow bunching." (Paich 1982) on fundamental technology conversions addresses many similar issues, although the focus is on a single architectural conversion to create a new product family rather than a series of product family rollouts. (Graham and Kreutzer 1983) treats a series of technology conversions, although as in Paich's analysis, the conversions are primarily production technologies as opposed to product technologies or product families. (Production and product always to some extent shift together; a new production technology should motivate product redesign to take advantage of it.)

[24]Forrester's widely discussed but unpublished "Corporate Growth Model" shows this behavior.

[25](Paich's 1986) has studied a case study of a saturating market.

[26]Early release in a multiphase design and construction process leading to successively lower quality is a major factor in the behavior of Pugh-Roberts Associate's shipbuilding model described in (Cooper 1980).

[27](Uttal 1987) synopsizes recent academic and business thinking about parallel versus serial product development.

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