STRATEGIES FOR CONVERTING TO NEW TECHNOLOGIES

Computer Graphics in the Color Printing Industry

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ABSTRACT

A number of challenges face firms that need to decide when and whether to convert from traditional technologies to new computer-based technologies. Such is the case with lithographic setup shops, which prepare photos for color printing; they must choose between continuing the traditional craft methods or acquiring digital image-processing equipment. Pioneering firms can be saddled with experimental, undependable, and expensive prototype systems. Rapid technological changes still occurring in digital systems can allow competitors who invest later to obtain cheaper, more effective equipment. But firms investing later may find themselves paying for the large investment just when most competitors are established in the new technology and competition has forced prices and profits to low levels.

In order to create an organizing framework for analyzing and developing conversion strategies for these firms, we worked in collaboration with Inter/Consult, the project's sponsor, to build a system dynamics model of the color prepress industry, its market, and a typical firm. The primary purpose of the model is to provide a clear understanding of the impact these major capital investments will have on the profit structure of lithographic setup shops and to help these shops develop effective conversion strategies. A secondary purpose of the model is to aid digital image-processing equipment suppliers in understanding their market and to provide them with a tool for generating alternative scenarios given different assumptions about economic trends, technological developments, prices, market size and composition. The model serves as a strategy support system that allows clients to derive scenarios explicitly from causal assumptions and to evaluate alternative investment strategies.

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Rapid advances in technology are transforming the structure and the nature of many industries, presenting firms with difficult challenges. Boundaries between industries change over time, expanding and shrinking as new applications become available or firms in other industries capture or replace an older industry's market. Sometimes separate industries gradually merge as technologies developed for one industry find applications in new areas. The traditions, strategies, and technologies that firms have developed may no longer suffice to maintain their competitive strength.

Figure 1, based on slides developed by Nicholas Negroponte and Andy Lippman at MIT, illustrates technological changes in the computer, publishing, and broadcast industries [1]. Originally, each technology was entirely seperate; the circles did not intersect. But the industries have been merging gradually, as new products are created based on (or applicable to) the technologies of several industries; so the circles are moving together. The overlap of computers and broadcast media has produced computer animation systems and character generators for print displays on TV. The overlap of publishing and broadcast technologies seems ready to produce videotext services, having already produced information services such as stock market and credit reporting. When computers and publishing overlap, the results are word processing and automated typesetting. More recently, the overlap of computing and printing has produced digital color processing for printing, which is the subject of the case study reported here. For a wide variety of businesses the tools of the trade are changing rapidly, due to diffusion of new technologies from previously unrelated industries.

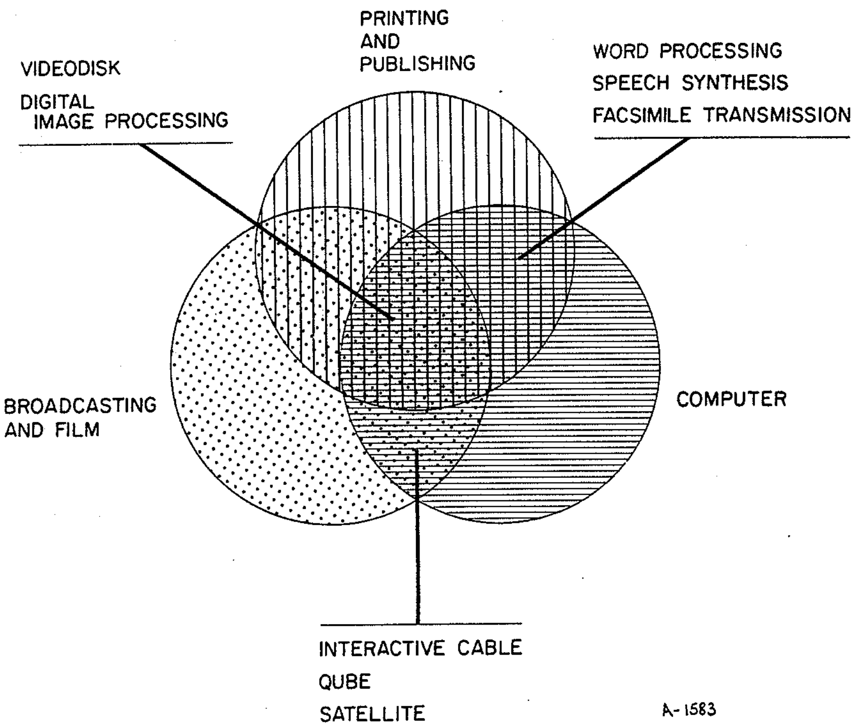

Figure 1. Technological Convergence of Three Industries Create New Applications (Based on material developed by Negroponte and Lippman.)

HISTORY OF GRAPHICS IN COMPUTERS

Originally developed for military and space uses, digital image processing has been just one component of the computer technologies that have been diffusing into many other industries. The history of digital image processing and interactive computer graphics can be traced back to Jay Forrester's Whirlwind Computer project in the early 1950s, which first used the computer-driven CRT (cathode-ray tube) display. Another significant development in interactive computer graphics, which occured during the

construction of the North American radar net during the SAGE air-defense program (also directed by Forrester), was the use of CRTs as command and control processors. Light pens could be used to touch the image of an airplane or other object on the radar screen causing the computer to track it as it moved through the territory. Since then, digital image processing has been substantially developed by NASA and the Defense Department for guidance systems for missiles, satellite surveillance, and the exploration of other planets.

Computers diffused rapidly into the civilian economy. Because of the intensive computation needed to create and modify images, however, computer graphics technologies have spread more slowly. The first such systems were expensive military flight simulators and specialized applications, such as processing satellite surveillance data. As computing costs steadily diminished over the decades, new applications proliferated to lower-cost systems involving standardized characters for automated typesetting, word processing, and superimposing text on TV broadcasts. The increasing power of computers is now making it possible to compose or manipulate entire images commercially. Today, computer-generated images are common in film, television, video games, and advertising, and they are starting to be used by the subjects of this case study, the companies that prepare color pictures for magazines and newspapers.

Industry watchers are anticipating rapid growth in automated offices, videotext, computer-aided design engineering, and manufacture (CAD, CAE, CAM), computer-aided architecture, and robotics, all of which can be linked to software and technologies developed in digitial image processing. In other words, like the color preparation industry, many industries are about to face the trauma of conversion to computer-based technologies.

THE COLOR PRINTING INDUSTRY

Similar to the computer industry, the printing industry has a distinct history with its own brand of technology, starting with the Gutenberg press in the mid-1400s. Wooden frames and blocks of movable type were used to press inked images down onto paper. From those printing blocks developed the highly skilled craft of engraving and lithography, where artisans would carve (or etch) their images on metal plates.

During the last century the traditions and descendents of those craftsmen formed the bases for what is now called a lithographic setup shop or a color prepress preparation shop. These shops produce the film that is now used to photoengrave the metal plates used in modern printing presses. Sometimes they are a division of a printing company; sometimes they are independent. Their customers come to them with color photographs and the outline of a page design, for example, for the color-printed cover of a magazine or catalog. These printed color pictures are actually composed of thousands of tiny dots usually in four basic colors. By juxtaposing these dots precisely, the eyes perceive the image as containing thousands of colors that subtly and continously blend together. The setup shops take the original photographs and text overlays, arrange the page layouts, and produce separate films of tiny dots for each of the four colors so that the final product will resemble the original. These shops also perform image modification such as airbrushing and color changes. The processes are laborious and demand considerable skill; so the industry is an ideal opportunity for computerization.

MERGING OF TECHNOLOGIES

In the past few years computer and printing technologies have come together so that computer image processing can now replace many of the traditional methods in the color-printing industry. Many assumptions about the upcoming changes in this industry are widely accepted. Digital image processing is expected to dominate the industry within three to ten years. The reliability and effectiveness of digital processing is expected

to increase far beyond that of manual processing as industrial experience with the technology increases. The cost of the equipment is expected to drop as the market and technology mature. Also, as the cost of the equipment drops and its effectiveness within firms increases, the cost per page job for the firms with digital equipment is expected to drop sharply.

Given precedents in other new technologies, however, unstable prices are expected for prepress jobs. When the number of units in the field nears saturation, the boost in productivity produces excess capacity, which results in widespread price cutting by firms attempting to gain market share. This drives the average market price toward the new, lower cost per job inherent in digital processing, which reduces the originally higher profit margin--the very same profit margin that is one of the main selling points of the equipment!

The expected changes in the marketplace due to conversion to new technologies pose a challenge to individual firms. Several strategies exist, each of which presents opportunities and dangers. Firms must decide what posture to take with respect to this conversion. Do they want to be pioneers on the forefront, who perfect the new technology? Should they wait until after the pioneers have made the major mistakes, determine the solutions, and then go in? Or should they wait even longer, until the technology matures, the market settles out, and little uncertainty remains?

A CASE STUDY: ELECTRONIC GRAPHICS FOR THE COLOR PREPRESS INDUSTRY

In order to develop an organized framework for analyzing conversion strategies, we have built a System Dynamics computer simulation model of the industry, the market, and a firm. The model examines investment strategies of lithographic prepress color preparation shops making the transition from traditional manual processing to electronic color page make-up systems. The project was initiated and sponsored by Inter/Consult, a consulting firm for the graphic arts industry.

SYSTEM DYNAMICS

System dynamics is a methodology and a body of knowledge about problem solving that revolves around the use of computer simulation models to test and design policies, much like a wind tunnel is used to design aircraft. More precisely, Edward B. Roberts, in Managerial Applications of System Dynamics, describes system dynamics as "the application of feedback control systems principles and techniques to managerial, organizational, and socioeconomic problems [2]." In the seminal text Industrial Dynamics, Jay Forrester explains how the approach "provides a single framework for integrating the functional areas of management--marketing, production, accounting, research and development, and capital investment [3]."

Once a computer simulation model is capable of replicating the historical dynamics of the problem being investigated, a variety of policy tests can be undertaken. The modeler can do experiments with the model that would be impossible, expensive, or risky in real life. "What if" scenarios can be simulated to compare how well alternative strategies fare under a variety of possible situations. Finally, new policies, strategies, and corporate structures can be designed that improve the performance of the system.

THE ELECTRONIC COLOR SYSTEMS MODEL (ECSM)

The Electronic Color Systems Model (ECSM) simulates the behavior of the color prepress industry. The primary purpose of the model is to provide a clearer understanding of the impact that major capital investments in new processing technology will have on the profit structure of lithographic setup shops, and to help these shops develop effective conversion strategies. A secondary purpose of the model is to aid suppliers of digital

image-processing equipment in understanding their market and provide them with a tool for generating alternative scenarios with different assumptions about economic trends, technological development, prices, market size and market composition.

The Electronic Color Systems Model (ECSM) contains six sectors. In this paper, only the first four sectors, summarized in Figure 2, will be active. The first three sectors represent the changing technological and business environment for the fourth sector, the firm. The remaining two sectors show additional dynamics which are of most relevance to producers of digital equipment, when technological advances enable expansion into secondary markets with less costly devices. That transition is in many ways similar to the successive generations of computers--mainframe, mini, and personal. But space does not permit discussion of such issues here. Figure 3 is an overdiagram that shows how the active sectors are interconnected.

Sector	Represents
Equipment market	Installed base of electronic color systems (ECSs) and their technological effectiveness.
Market size	Price per job effects demand for color setup work.
Market	Digital and traditional jobs compete based on price, delivery delay, and quality. The firm competes for jobs based on its relative price, delivery delay, and quality.
Firm	A typical color setup shop, with digital capacity and an investment capability for digital capacity; it responds to market prices and its own utilization of capacity in setting its price. It also generates indices of costs and profits.

Figure 2. Summary of Sectors in Electronic Color Systems Model (ECSM)

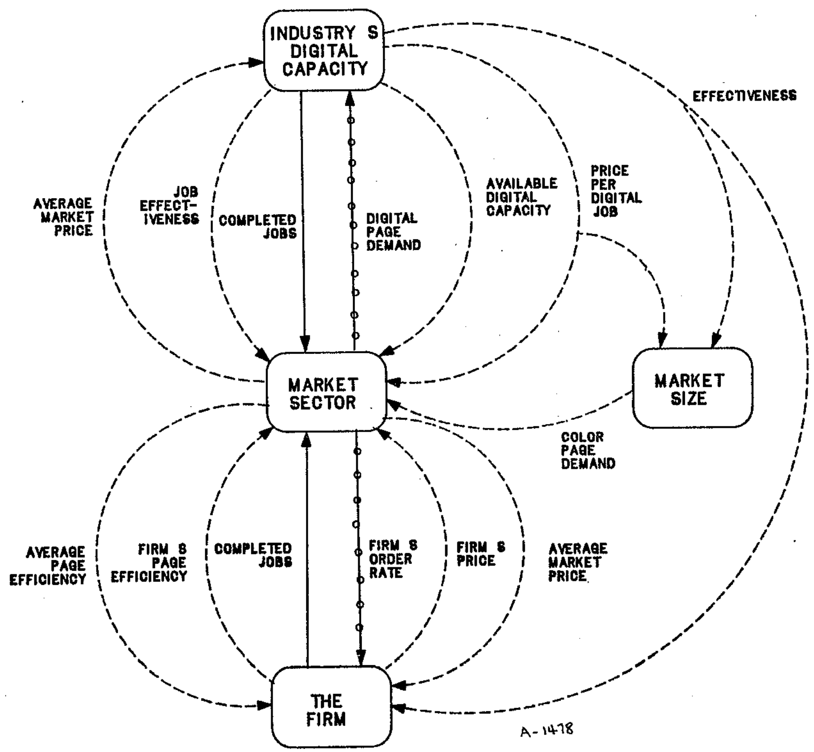

Figure 3. Structural Overview of ECSM

DYNAMICS OF THE EQUIPMENT MARKET: TECHNOLOGICAL IMPROVEMENT, THEN SATURATION

Figure 4 shows a policy-structure diagram of the equipment market sector. This format for diagramming was evolved by Professor John Morecroft at MIT for use with clients during model construction [4]. Each circle represents not just one equation, but all of the equations that define a single policy. This format is intermediate between a formal flow diagram (which contains far too much detail for conceptualization discussions

with non-system dynamicists) and the causal-loop diagram, which shows none of the levels and rates that are the foundations of the system's dynamics.

Figure 4 contains only two loops, one positive and one negative. The positive loop connects effectiveness, installation rate, and units in the field. It underlies a version of the classic "learning curve" behavior, where increasing scale of activity leads to technological improvement, which lowers costs and raises effectiveness, which in turn leads to a larger scale of activities.

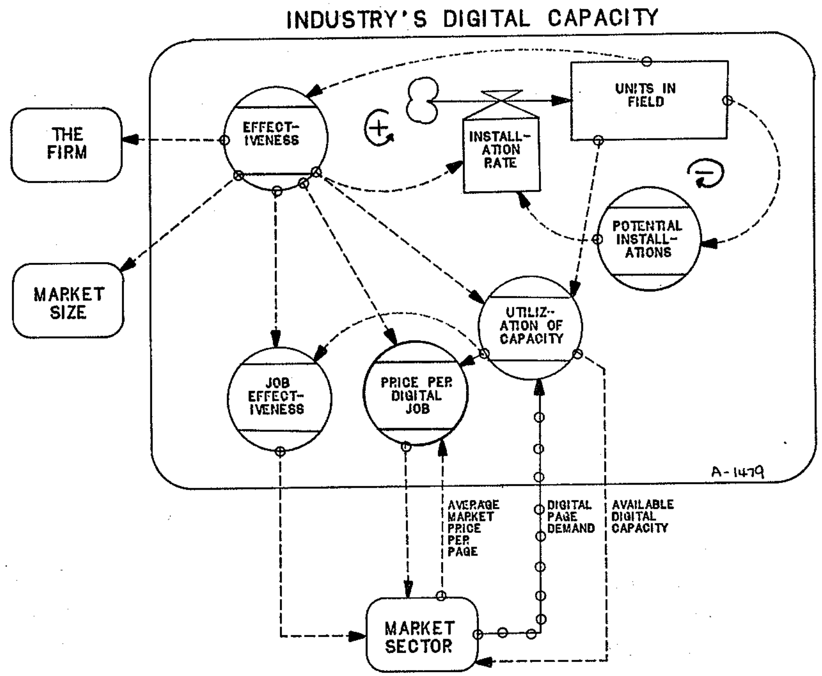

Figure 4. Policy Structure Diagram of Equipment Market Sector

The model expands the standard learning curve concept. For electronic color systems (ECSs), functionality as well as cost is very important. An inexpensive machine that is unreliable and difficult to understand and use is not a good buy. Also, technological improvements come from having units out in the field, so that experience using the units accumulates. This experience allows flaws in the hardware and software to be identified and corrected and also permits the designers to determine which features operators need for the system to be effective. Finally the costs to the manufacturer come down with more units in the field, not so much because of accumulated manufacturing experience, but because R&D costs for software are spread over a larger number of units. (A substantial amount of hardware for ECSs is based on off-the-shelf products of standard computer makers.)

The negative loop in Figure 4 connects units in the field, potential installations, and the installation rate. The installation rate is constrained by the finite size of the market for ECSs. In the extreme, if everyone interested in electronic color systems had already bought one, then sales and installations of new units would be zero. (A more elaborate model might deal with replacement purchases for obsolete equipment, but such refinements must await an additional project. This assumption is plausible here because the average lifetime of the equipment is longer than the duration of the industry transition being studied.)

Figure 5 shows a simulation of the equipment market sector. As time progresses, operating experience accumulates, leading to improvements in the effectiveness of the technology. As confidence in the technology increases, the installation rate increases, thereby accelerating the rate of increase in the effectiveness of the technology. This positive feedback loop alone would produce exponential growth in the units in the field. This happens only during the early part of the simulation,

because, as the number of installed units increases, the number of potential intallations decreases, forming a negative feedback loop that constrains the growth of the industry. So loop dominance shifts from the positive loop in the beginning to the negative loop after the middle, which creates the "S-shaped" growth of installed units.

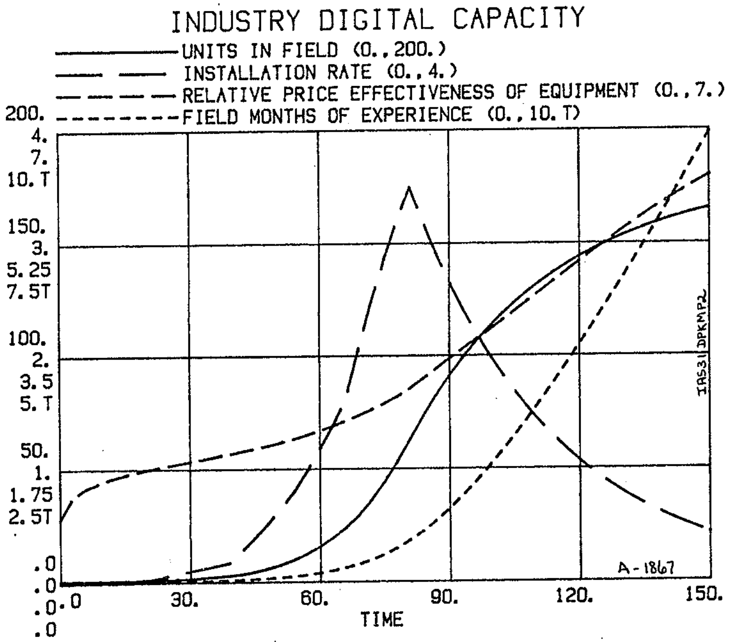

Figure 5. Simulation of Equipment Market Sector

DYNAMICS OF THE COLOR MARKET -- CONVERSION AND OVERCAPACITY

Figure 6 shows a policy structure diagram of the market sector, in which the model represents how supply and demand for color preprocessing influence its price. The market sector also compares the prices and effectiveness of the firm to the market averages to determine its order rate for jobs. (This will be discussed in the next section.) The market sector can be thought of as mediating between the equipment market sector (and thus the installed digital capacity) and the market size sector.

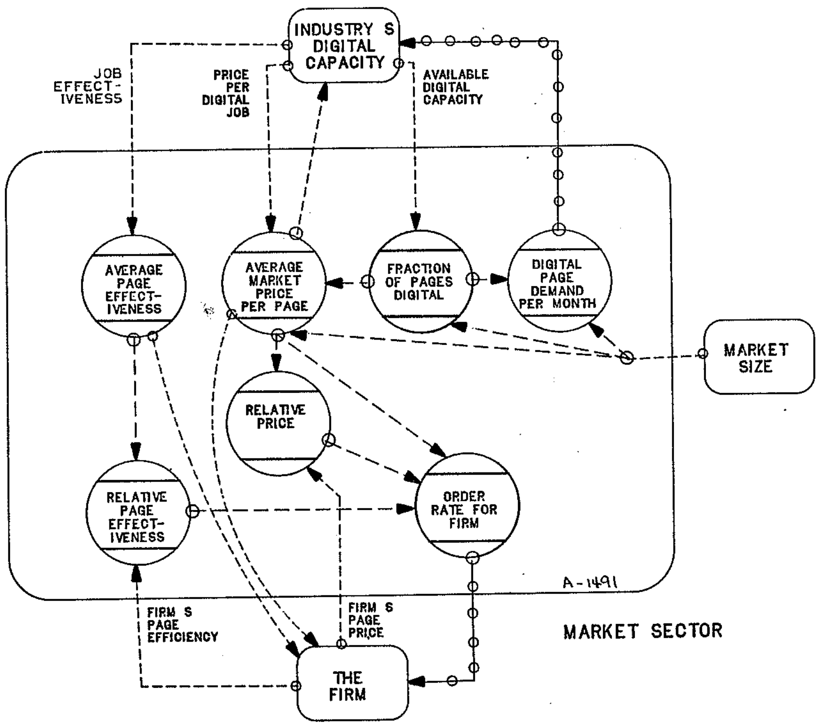

Figure 6. Policy Structure Diagram of Market Sector

Figure 7 shows variables from the market sector, from the same simulation that generated Figure 5. In the beginning, when only a few pioneers have electronic color systems, the demand for color prepress work is roughly equal to the supply, and the price per digital job is very close to the average market price (even

though the cost per job for digital processing has already dropped much lower than the cost per traditional job). There is only slight motivation for those with digital systems to reduce their prices: the digital price is slightly lower than the average market price because the trade shops with new installations are building up their order rates to their new, higher capacity.

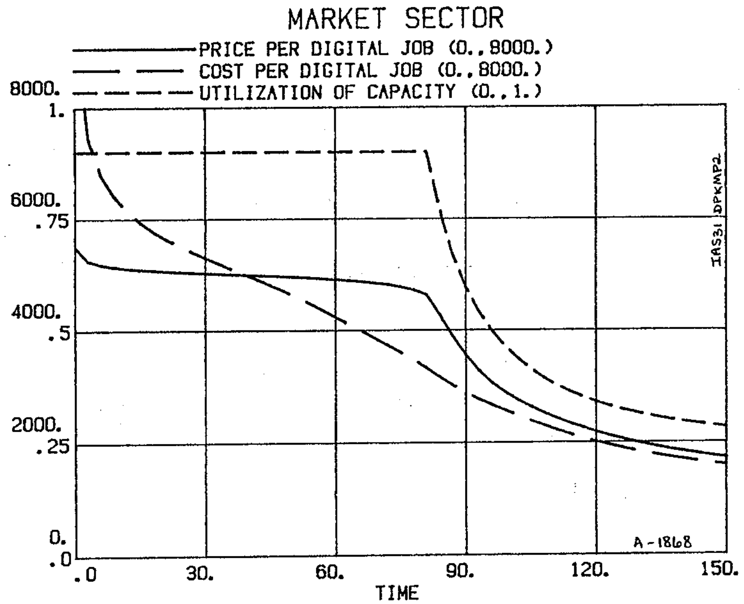

Figure 7. Simulation of Market Sector

By the middle of the simulation, the cost of electronic color systems is dropping (as modeled in the industry digital capacity sector) and the number of installations is increasing exponentially. But when the fraction of jobs done digitally approaches its maximum, which it reaches by month 80, excess capacity begins to spread throughout the industry.

This initiates pressures causing price cutting and "shake-outs" that are prevalent in many new industries. Firms cannot remain cost-competitive without the new technology, so many remaining firms convert even after excess capacity is manifesting itself throughout the industry. As more firms convert, excess capacity gets worse increasing pressures to cut price, which in turn puts pressure on remaining firms to convert. This positive feedback loop is exacerbated by the long delays from the decision to convert, to ordering, delivery, and finally to bringing new equipment up to full capacity.

It should be noted that in real life there are several ways for a firm to stay in business while avoiding a direct conversion to digital technology. Since the color prepress industry relies on extensive personal contact with publishers, successful firms that have already converted may either buy out unconverted firms or take them on as junior partners to act as marketing organizations for the firm with digital capacity. Also, there will be room in the industry for a few traditional firms to specialize in those jobs which are inappropriate for digital systems.

Alternatively, firms with excess digital capacity may accept jobs from other firms at lower than manual cost. The part of the electronic color system (ECS) that converts photographs to digital information is much less expensive than the part that performs image modification. As a result, many firms own the former (the "scanner") without being able to purchase the latter. But as scanners become able to transmit the digitized information over telephone lines, many "retail" shops can send their jobs to a single "wholesale" firm with a full ECS. Such developments have already begun in architectural firms converting to computer-aided design (CAD) systems.

Some words are in order about the technologies and the industries to which the preceding dynamics apply. Overcapacity

prompts a rapid shakeout in industries where the new technology is dramatically superior to the old, and that superiority is directly reflected in the competitiveness of the firm. So architectural or engineering firms using CAD should show very similar dynamics. Note, too, that price is not the only competitive variable; CAD/CAM is catching on very quickly among automobile manufacturers, not because they gain a significant price advantage from digital designing, but because CAD/CAM offers much more timely updating of designs.

By contrast, there seems to be no danger of widespread overcapacity for word processing users. Most firms do not accrue any major competitive advantage by converting to electronic word processing; the conversion decision is a simple cost/benefit decision with relatively less impact on the overall performance of most firms.

THE FIRM SECTOR AND POLICY ANALYSIS

The sectors just described provide a background environment used in testing the consequences of the different strategies an individual firm uses to make the transition to new equipment in an industry that is itself changing. Figure 8 shows a policy-structure diagram of the firm sector, which represents the policies and conditions within an individual firm: digital capacity, order backlog, work quality, price and indices of cost and profit.

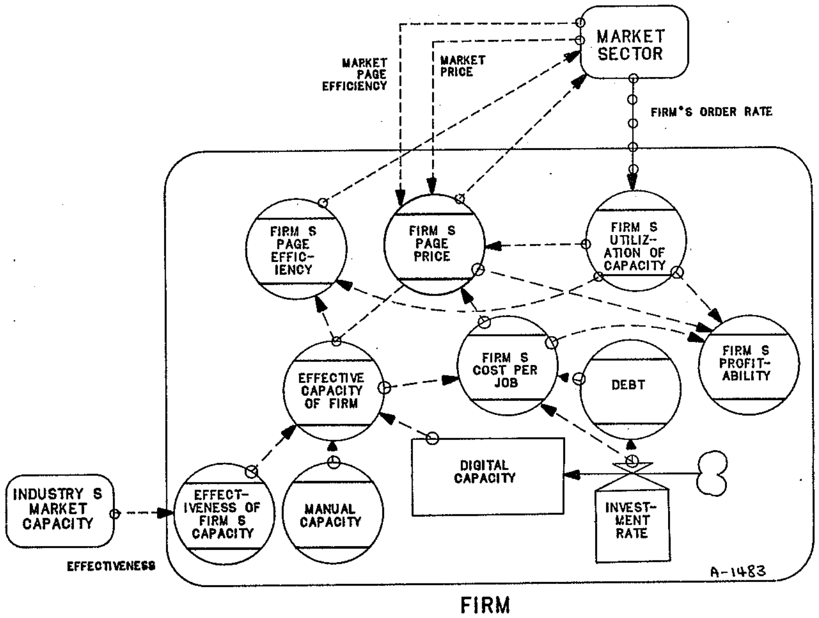

Figure 8. Policy Structure Diagram of Firm Sector

The following sections describe generic scenarios generated by the model. One way the model can contribute to strategy development is to provide clear pictures of the industry's behavior patterns the firm is likely to encounter. The model will only generate behavior that results from a consistent and explicit set of assumptions about causes and effects, and those assumptions along with the behavior can be examined for plausibility--an additional "reality check." (By contrast, without a mathematical model, it is easy to posit plausible-looking behavior that could not result from any set of plausible assumptions.)

The model also offers a method of evaluating different transition strategies a firm might adopt. For example, the simulated investment strategies for the firm all take place in the same market environment. The results within the firm, however, are distinctly different due to the timing of the investment decision.

EARLY COMMITTMENT--IMMATURE TECHNOLOGY REDUCES PROFITABILITY

One transition strategy that might be explored by an aggressive firm wishing to jump ahead of the competition is to buy the newest, most sophisticated equipment at the first possible moment. If the equipment is functional, the firm can realize substantial profits, as it charges traditional prices while its processing costs are reduced.

On the other hand, if the technology is immature, operating costs can be enormous. Often, the high initial cost of the system will not be repayed rapidly because the machine is not fully utilized. Newly developed systems sometimes stop working for mysterious reasons, and, surprisingly, sometimes a new system will sit in the corner unused when a firm is too busy to expend the manpower to learn to operate it. The problem is compounded if the system's educational materials haven't been extensively field-tested and aren't yet effective. Additionally, if a firm is locked into obsolete equipment, the firms that waited before buying can put the pioneering firm at a competitive disadvantage by using cheaper, more effective equipment.

Figure 9 shows a simulation of the early investment strategy. The firm buys an electronic color system in month 2, and it is "locked in" to its original level of technology, i.e., there is no increase in its effectiveness as the industry gains experience with digital technology.

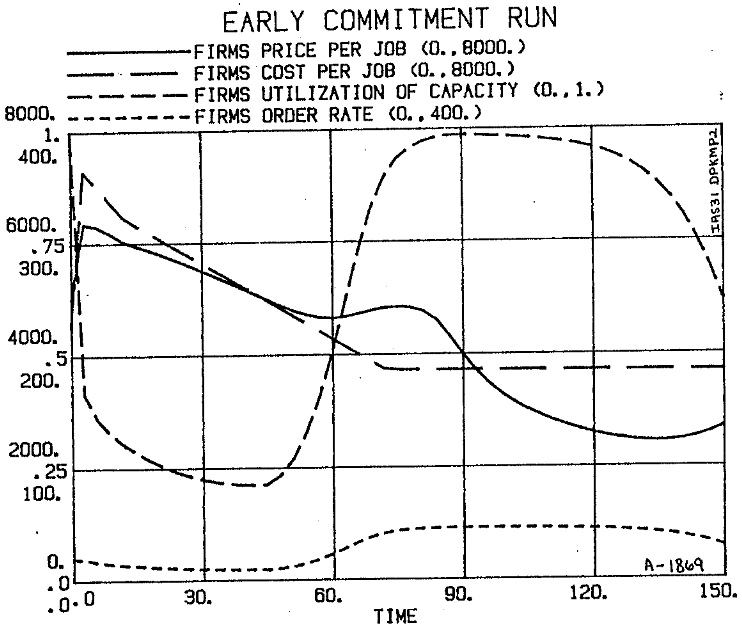

Figure 9. Simulation of Early Committment Strategy

A major feature of this simulation, and indeed all of the strategy evaluations, is the "window of opportunity." For this firm the window opens at month 45, when digital processing costs for a new unit drop below the cost of manual processing while the price charged for processing has not yet dropped. The window closes around month 92, when widespread overcapacity drives down prices. With the early investment strategy, the window of opportunity slams shut particularly hard; since most of the industry converts to equipment that is more cost-effective than the firm's equipment, when price-cutting begins, the early-investment firm will be hit harder than most.

LATE INVESTEMENT--TOO CLOSE TO SHAKEOUT TO RECOUP INVESTMENT

The firm could wait until the technology matures. This plan avoids the danger of being locked in. The risk, however, is that the companies which have already converted successfully will force the traditional firms out of business by reducing their prices to their new lower costs when excess capacity develops in the industry. If the traditional firms survive the price transition and then invest, slender profit margins and thus erratic cash flows can make financing the equipment both burdensome and risky.

Figure 10 illustrates the late investment strategy with a simulation that delays digital acquistion until month 110. This strategy avoids the early lock-in effect. The equipment purchased is excellent and embodies a lower processing cost. However, the firm has also missed the window of opportunity. It is still paying the extra conversion cost when prices are pushed to the new cost floor by those firms that have already purchased advanced systems and payed for them when their profits were higher. Note that the firm invests when there are still apparently good profits to be made--the price has just barely begun to be forced down by the burgeoning excess capacity of the industry. Such late investment doesn't miss the window of opportunity due to the immediate profit picture, but because the price/cost gap will close before the investment can be recouped. At best, then, the late investment strategy allows the firm to stay in business. Depending on the smoothness of its conversion costs and the competitiveness of the market, it may not even be able to do that.

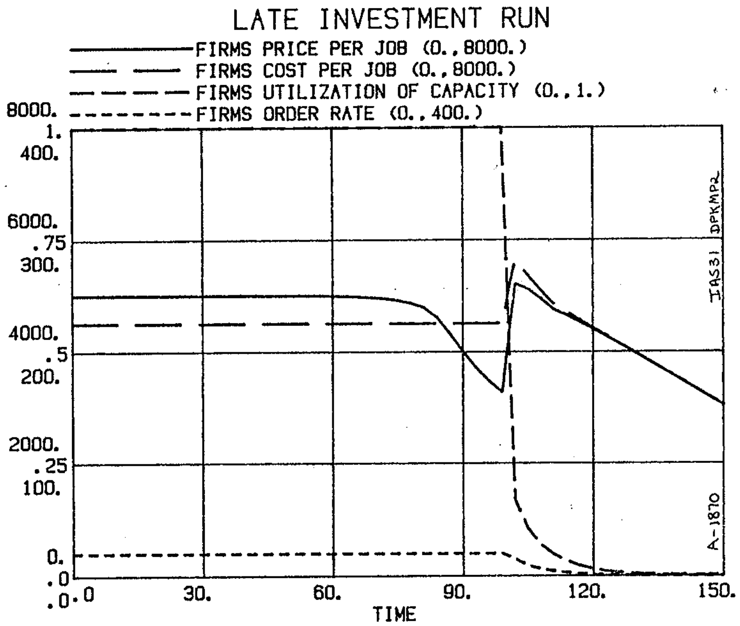

Figure 10. Simulation of Late Investment Strategy

HITTING THE WINDOW OF OPPORTUNITY -- SUCCUSSFUL CONVERSION

If investing too early locks a firm into obsolete equipment with high conversion cost, and investing late forces the firm to endure conversion costs while the industry is undergoing price cutting there must be a better strategy somewhere inbetween. A moderately agressive firm whose managers watch the evolution of the equipment technology closely might take advantage of the policy of some equipment makers of regularly enhancing the software and making new, add-on equipment available. Regular technology updating avoids, to some extent, the problem of older equipment being locked into early technology. So technologically sophisticated firms may wish to invest early and acquire expertise and new customers in hopes that the "updatable" equipment will remain competitive. Firms investing after the

pioneer stage of the industry are also able to convert more quickly because the skilled labor and experience of the pioneers are available.

Figure 11 illustrates a highly successful conversion strategy by a firm purchasing digital equipment at month 30 just as the window of opportunity is opening. After recovering from its conversion costs by month 60 the firm's operating costs continue to fall until month 110 as it continues to take advantage of improved efficiency due both to the equipment supplier's and its own learning curves. This allows the firm to retain its exceptional profit margin and expand its customer base even as prices are falling.

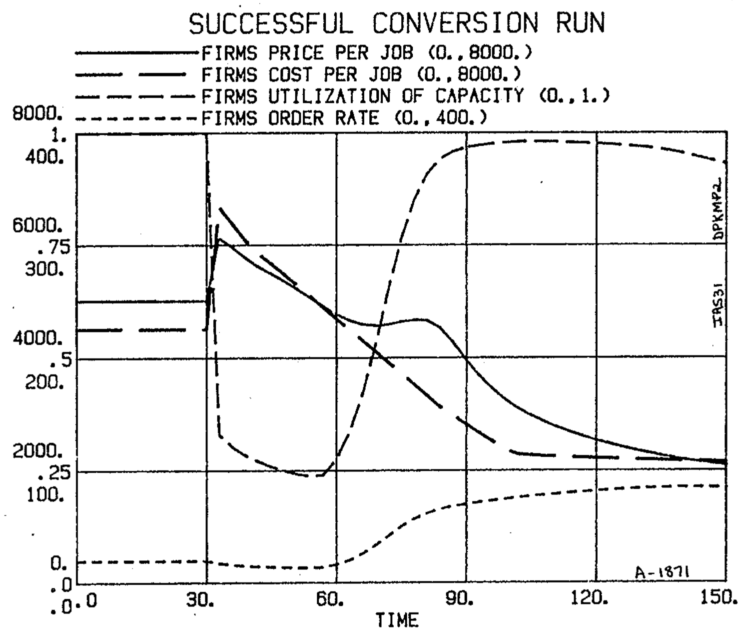

Figure 11. Simulation of Succesful Conversion Strategy

With no additional investment even this successful firm losses its competiveness by month 140 as it is no longer able to keep up with the most highly advanced systems available during the 90 months following its investment.

INCREMENTAL INVESTMENT--HITTING THE WINDOW OF OPPORTUNITY AND FOLLOWING THROUGH

The firm which successfully invested just as the window of opportunity was opening up has another opportunity available to it. That is to follow through with additional system purchases or major expansions with profits from the first conversion. This incremental investment approach is perhaps the most attractive of the investment strategies discussed here. A firm might purchase an image processor with limited features, then add workstations, scanners, and sophisticated software packages as its experience and order rate grow. These major expansions and new systems improve a firm's capability much more than the enhancements and upgrades to an already existing system discussed in the previous section. For this stratagy to be effective one must assume that newer systems will be compatible with older ones and that operator skills will be transferable.

Figure 12 illustrates the incremental investment strategy, in which the firm purchases digital equipment at month 30 and additional digital equipment once every fifty months after that. In effect, this is a policy of trying to keep one step ahead of obsolescence. The three investments have quite different effects on the firm's competive position. The first investment is the entree into electronic color systems; the investment provides experience and begins to build order volume. Profits are substantially improved, until improvement in ECS technology and price cutting begin to threaten profits. The second investment remedies the situation by assuring that the firm's cost after the transition will be as low or lower than those of its competitors. The third investment does not provide additional technological or

cost advantage, but does continue to expand the size of the firm--revenues expand even after an era of price-cutting.

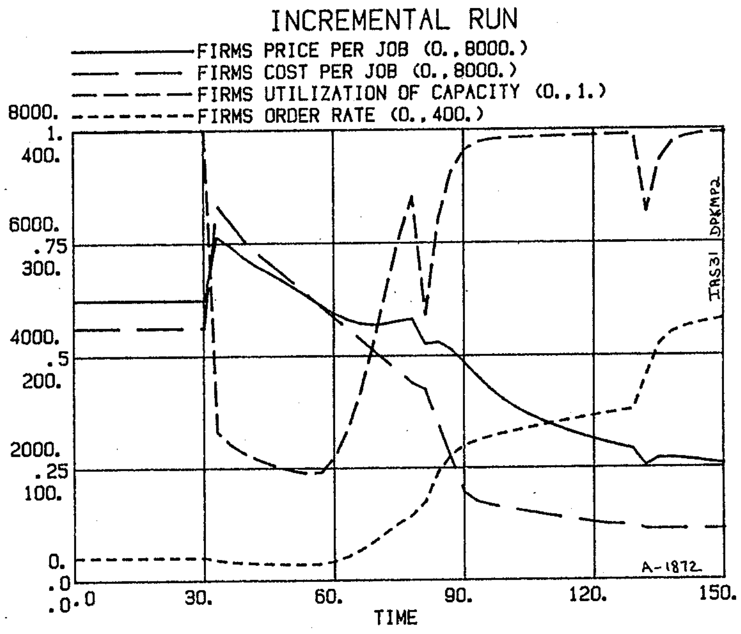

Figure 12. Simulation of Incremental Investment Strategy

By constantly increasing its own effectiveness, the firm competes with increasing effectiveness and decreasing price industrywide. The run shows that the firm's constant price cutting leads to ever-increasing orders.

There are a number of ways a real firm can attract business as its capacity expands. One, of course, is to attract customers one at a time with more favorable pricing and superior service.

Others involve taking over unconverted firms and their customer bases either through outright ownership or through various forms of subcontracting to the unconverted firms, which in effect become purely marketing organizations.

Naturally, there are pitfalls to continual expansion. For example, development technology for photographs advanced to the point where chains of specialized shops using small developers could promise overnight developing. One of the more prominent chains went bankrupt when, after taking an unexpectedly long time to build up a customer base, its cash commitments for expansion exceeded its revenues, which were already depressed by the state of the economy.

All in all, the scenarios analyzed here indicate that the best strategy is to convert during the window of opportunity. This result may seem trivial at first glance, in that the best strategy is a compromise between two extremes. But the triviality is more illusion than real. The model provides fairly specific characterizations of what to look at to determine where the industry is relative to the window of opportunity. The opening of the window occurs when only a few other firms are fully utilizing the new equipment. The window for profitable investment is already closing when a substantial fraction of firms in the industry have converted--this is <u>before</u> a shakeout occurs. And even firms that failed to convert until after the shakeout has started will be given considerably more impetus by the model to make realistic plans.

CONCLUSION

As the work on strategy evaluation evolved, the "window of opportunity" concept became more and more central. Also it became clear, as the remarks from time to time indicate, that the results should apply to many industries. Before finishing the substantive results, then, it would be well to ask "under which circumstances will there be a window of opportunity to take

advantage of?"

Figure 13 summarizes four prerequisites for the existence of a window of opportunity. First, as previously mentioned, the technology must have a major impact on the firm's competitive performance, otherwise there will be no shakeout. Second, the technology must have prospects for major improvement. This must be taken relatively, for everything is improvable to some degree, but if there is no need to worry about large improvements in later models, one can convert to a new technology whenever it appears cost-effective. For example, few of us would postpone buying a car for next year's models--we simply don't expect enough improvement to outweigh the inconvenience of postponement.

Technology has major impact on firm's competitiveness
Technology has prospects for substantial improvement
Technology expands scale of efficient production
Intermediate speed of penetration

Figure 13. Prerequisites for the Window of Opportunity

Third, the technology must expand the scale of production. This is actually a requirement not only of the technology, but of labor and business practices: converting to a new technology must increase the amount of production desired by firms (otherwise conversions will reduce the number of employees rather than produce overcapacity). When AT&T converted to electromechanical switching during the 1930s and 1940s, the conversion did not produce overcapacity; the switchboard operators were gradually discharged. But for lithographic setup shops, once an electronic color system is in place, strong pressures exist for individual firms to try to utilize it fully by expanding operations. And a number of factors make it difficult to reduce "manual capacity"--i.e., skilled artisan employees. Union pressure, personal ties, and uncertainty about the new technology all motivate management to retain employees and attempt to expand the business. When the entire industry retains both employees and digital capacity, the conditions for a shakeout are created. (This effect can be mitigated to some extent if the drop in prices cause a large increase in the number of color jobs due to conversion from customers for black and white jobs. The model has structures to simulate and test these dynamics, however, they were turned off for the runs in this paper.)

Finally, technology must not penetrate its user market very rapidly (two months) or very slowly. If an industry adapts a new technology all at once, the window of opportunity is gone, but then so is the question of when to convert. By analogy, no child obtained any advantage from being a trend-setter with hula-hoops, because everyone had one. At the other end of the spectrum, if so few firms convert that the technology never takes off (even if it is ultimately improvable), there is no shakeout and no window of opportunity.

Turning away now from substantive results, the project had some interesting methodological results as well. This study was among the first applications to use Morecroft's policy-structure diagrams extensively for model conceptualization, client interaction, and research organization [4]. Even though the consultants with whom we worked had no formal training in System Dynamics notations, the diagrams provided a very efficient focus for discussions of both the subject matter and the progress of the project. Moreover, in a good example of technological synergy, the diagrams were implemented on a CAD/CAM system, so they were easily kept both up-to-date and neat from the very beginning of the project [5].

Unlike many of the classic system dynamics studies, the model's primary use was to generate a plausible scenario to aid in understanding the system. Using a dynamic simulation model to generate scenarios seems to offer some advantages over the

"mental generation" of static scenarios practiced in some prominent think-tanks: The model scenarios follow demonstrably from the present time. By contrast, with a static, mentally-generated scenario, one can have little confidence that there exists any plausible sequence of events that would bring the scenario into existence. A trivial example: One can easily imagine a world in which everyone is superbly educated, and productive enough so that no one starves. While this is an inspiring scenario, its most important aspect is missing--how do we get there from here?

The research reported here was sponsored by a consulting company, Inter/Consult, that wanted to be able in turn to use the model with their clients. Those clients need a way to gain confidence in the model without having to build it, or to understand System Dynamics concepts. Responding to this need, a follow-up to this project is developing a user interface to allow clients to examine or modify parameters in the model and simulate it with minimal guidance [6]. The clients seem to appreciate the ability to adjust the model toward having the same numerical characteristics as their own operations.

Although the modeling effort generated the several interesting methodological results, it also achieved its principal goal, which was to improve the understanding by various clients of the issues surrounding the decision to convert to new technologies. Although project results like "improvement of understanding" are certinly difficult to assess, the authors' subjective impressions are that the study contributed an enormous amount of clarity and structure to a situation that was previously little more than a loosely related tangle of worries about the future. Indeed, those involved in the project are beginning to exhibit the "that's so obvious that we must have always known it" syndrome that too often hides the true utility of system dynamics studies.

ACKNOWLEDGEMENTS

The modeling project whose results are described here grew out of a class project under the auspices of the MIT Corporate Research Program in System Dynamics [7], which was created by Prof. John Morecroft [8][9]. The work was supported both financially and epistomologically by David Goodstein and Gregory Van Buren of Inter/Consult. Robert Lucadello performed part of the original modeling work. The policy-structure diagrams were executed by David Kreutzer and Janet Gould with assistance from Scott Ewing on a Designer System donated to M.I.T. by Computervision Corporation and made available for use by Professor David Gossard [5]. Diane Senge drew Figure 1. Andrew Plummer assisted with preparation and editing.

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