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THE DYNAMICS OF A FLEDGLING HIGH-TECHNOLOGY  
GROWTH MARKET

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Understanding and Managing Growth Cycles

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THE DYNAMICS OF A FLEDGLING HIGH-TECHNOLOGY GROWTH MARKET

Abstract

This paper presents a system dynamics model of the fledgling market for automated storage and retrieval AS/RS systems based on a case study of a leading firm in the industry. The model examines how marketing effort, capacity expansion, and industry reputation interact to produce growth cycles of 8 to 9 years' duration in demand and capacity for AS/RS systems. A series of partial model simulations is used to explain how the growth cycles are generated by the feedback structure and behavioral assumptions of the model. A policy experiment is presented to show how a mature firm in the industry can influence the growth cycles to improve its financial performance. Finally, the feedback structure governing market diffusion and capacity expansion is generalized to other high-technology products and markets.



## INTRODUCTION

Innovative products based on new technology often meet considerable market resistance before they are widely accepted and adopted by users. It takes time to persuade customers that the new technology is a worthwhile advance on the technology it supercedes. The product may not, in the minds of customers, be clearly superior to the older-technology product. The reputation of the product may suffer during the early phases of market growth due to inexperienced or unscrupulous producers who turn out inferior and unreliable versions of the product. Companies in such a fledgling industry face the difficult task of assessing the growth potential of the market. They must discern whether market resistance to the adoption and sale of the product is due to genuine limitations in the size of the market or to temporary setbacks in the product's image and perceived usefulness. Failure to distinguish temporary setbacks from true market saturation can easily lead a company into overly pessimistic sales forecasts, which become self-fulfilling as the company restricts capacity expansion in line with the forecast.

This paper examines the long-term dynamics of one particular fledgling high-technology growth market, the market for automated material handling systems. A system dynamics model of the market is presented that was developed for a leading company in the industry. The model focuses on technology diffusion and the dynamics of capacity expansion resulting from the entry of new firms into the industry. New firms tend to operate as parasites on the demand created by more mature companies. They expand

capacity on rather speculative grounds and can damage the reputation of the industry by producing unreliable systems. These characteristics of the competition are shown by the model to produce 8- to 9-year growth cycles in the fledgling industry, which can greatly distort an accurate assessment of market potential. Policy experiments with the model show that a mature company should be prepared to expand promotional marketing effort during periods of market stagnation while excess competitive capacity is worked off and industry reputation recovers. Such a "leadership" marketing policy tends to stabilize the growth cycles and increase the industry's growth rate.

The model may be viewed as a self-contained behavioral theory of market diffusion and capacity expansion in emerging industries that produce technically complex products. A number of high-technology industries might fit this description, particularly those making sophisticated equipment for the office and factory of the future. The model-based theory represents an addition to the market diffusion literature of Bass (1968), Dodson and Muller (1973), Mahajan and Peterson (1973), and Rogers (1962) by showing market structure that can create an illusion of saturation in a growth market.

#### A BEHAVIORAL MODEL OF FLEDGLING MARKET DYNAMICS

##### Background on the Automated Material Handling Industry

Automated material handling systems (also known as automated storage and retrieval AS/RS systems) are used by manufacturers, distributors, and

retailers to store and retrieve components from factory, warehouse, and point-of-sale inventories. A typical example of such a system would include a rack-storage structure (essentially a large matrix of storage bins) and an automatic mechanical device for moving up and down the storage isles to locate, select, and retrieve components from designated locations. Systems are technically sophisticated. They involve a blend of advanced mechanical, electrical, and computer-systems engineering. They are also expensive and time-consuming to make. An automated storage and retrieval (AS/RS) system to be used in a manufacturing plant might cost several million dollars and take more than a year to build and install once the design and specifications have been agreed to.

AS/RS systems are intended to replace manual material handling methods, in which human operators locate and retrieve components from storage areas (sometimes with mechanical assistance from cranes and forklift trucks). Their primary virtue, therefore, is in labor savings. These savings, however, must be traded off against the reduction in flexibility of automated storage and retrieval (the machine cannot readily cope with errors in component location) and the inherent complexity of the technology. It takes a highly skilled workforce to manufacture, service, and maintain a reliable system. Moreover, the large capital cost of a system makes automation difficult to justify. For these reasons automated material handling technology has not yet been greeted with unanimous enthusiasm. It is still a fledgling technology.

Marketing of AS/RS Automated Material Handling Systems

Marketing of AS/RS systems is generally thought of as a three-stage process. In the first stage, called conditioning, customers learn about the technology and become interested in the product. Automated material handling systems are complex, and a considerable amount of time can be spent in conditioning customers before they are ready to make a commitment to purchase. In the second stage of marketing, customers request studies to identify their system needs. Studies can take six months or more and lead to the definition of a material handling system tailored to the customer's needs. In the third and final stage, completed studies are opened to competitive bidding.

Competition in the AS/RS market is particularly strong from new companies in the industry, which are inexperienced and compete aggressively for contracts, often by underbidding both on price and lead time. Further, new companies are parasites on the market created by the more mature companies. They enter the bidding process but do little to generate and foster interest in AS/RS technology in the early stages of marketing. By contrast, mature companies establish their own base of interested customers and operate as though mutually independent in the market.

Industry reputation is an important aspect of the market. Many inexperienced companies have entered and left the industry during the last decade. Some of these companies have survived for four or five years on contracts that have been unrealistically bid. In many cases the final



installed material handling system has not matched customer expectations, has been plagued with problems, or has failed to work at all. Project failures undermine the reputation of the industry as a whole.

#### Overview of the Model

A system dynamics model of the AS/RS market was developed as a tool for understanding how marketing effort, competition and industry reputation interact to shape the growth of mature companies in the industry. The model depicts the market as it might be seen by a typical mature company, and it can be used to analyze policies that such a company might use to control market growth to its own advantage.

The market consists of customers who must first be informed of the product and who ultimately purchase a system by selecting one of several competitive bids from competitive AS/RS suppliers. Particular attention is paid to new firms that compete at the bidding stage, when a committed customer has been identified, but do not promote the technology or undertake feasibility studies. The model examines the factors that influence the startup of these new firms and their competitive bidding behavior.

#### Interest and Reputation Subsystem--The Diffusion Process

Figure 1 shows the diffusion process of the model, using system dynamics flow diagramming symbols.<sup>1</sup> The number of customers interested in the technology increases as a result of the mature firms' promotional

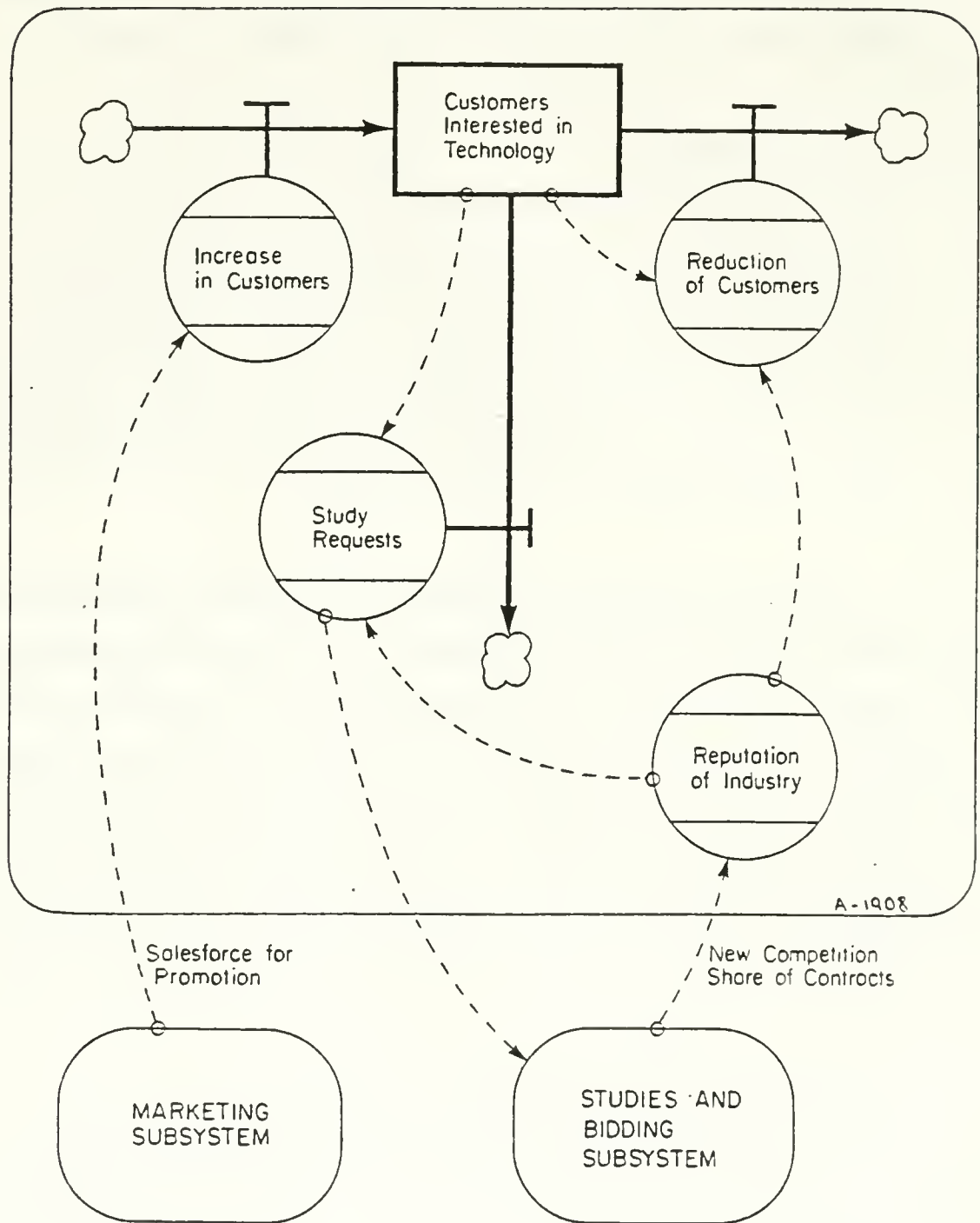


Figure 1. Interest and Reputation Subsystem

activities during the "conditioning" phase of marketing. Customers learn of the product from advertising and contact with salesmen (telephone calls and presentations), so that the inflow of customers increases in direct proportion to the sales force allocated to promotion. Reduction of customers represents a natural loss of interest. In the absence of sustained marketing effort, the number of interested customers will fall as the impact of sales contact or advertisement wears off. Diffusion of this fledgling technology, therefore, depends on continual replenishment of transient customer interest rather than spontaneous creation of interest through word-of-mouth.

Study requests are assumed to be generated in proportion to the number of interested customers. A study request leads to a feasibility study that specifies the AS/RS system best suited to the customer's needs. Industry reputation plays an important role both in influencing the proportion of customers who request studies and the rate at which they lose interest in the technology. If reputation is low, perhaps because recently installed systems have failed to live up to expectation, study requests will decline, and customers will quickly lose interest in the technology. If reputation is high, the reverse is true.

Executives in mature companies believe that a major factor in determining reputation is the average experience of firms in the industry. AS/RS systems are so technically sophisticated that customers are rarely in a good position to judge the merits of systems offered by alternative

vendors. New firms with the least experience of building and installing the systems are the most likely to supply a system that fails to meet customer expectations. To capture this idea, the model relates reputation to the share of contracts won by new competition. The greater new competition's market share the lower industry experience and reputation, and vice-versa.

#### Studies and Bidding Subsystem

The studies and bidding subsystem models the conversion of study requests into contracts to build and install AS/RS systems. In figure 2, study starts, which are equal to the number of study requests, flow into a level of projects under study. Under normal conditions, projects remain under study for six months. The company that undertakes the study prepares a detailed proposal describing an AS/RS system to satisfy the customer's material handling needs.

The customer takes the proposal and solicits competitive bids from a variety of AS/RS vendors. The model focuses on the decisionmaking process of customers selecting among bids from new firms and the mature firm that originally undertook the study.<sup>2</sup> Customers select a bid on the basis of price, performance, and quoted lead time. However, due to the technical complexity of the product, it is very difficult for customers to differentiate the price/performance specifications of alternative vendors. It is also difficult to know in advance whether the quoted lead time (often more than a year) is accurate or the result of misinformed thinking and

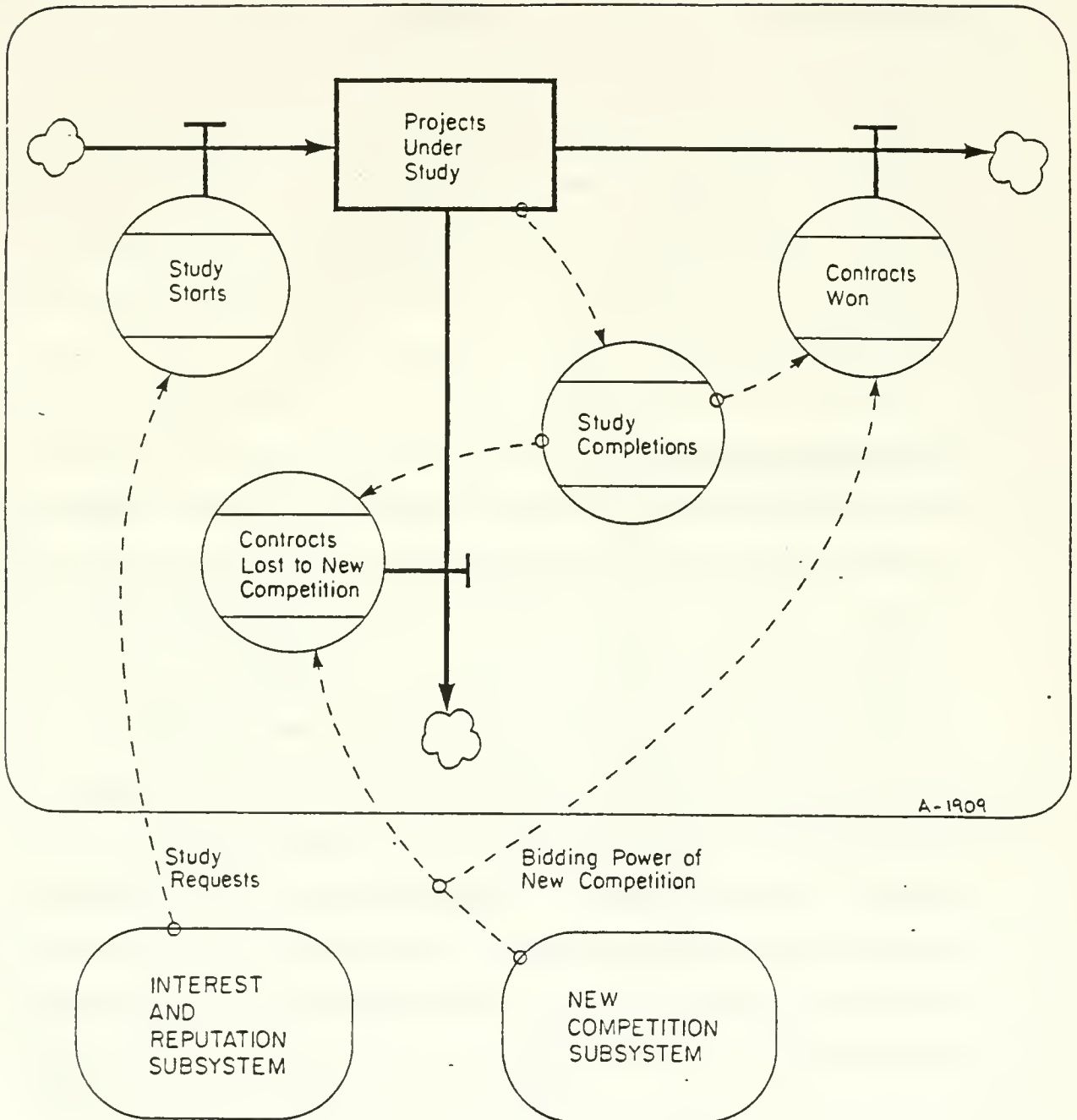


Figure 2. Studies and Bidding Subsystem

inexperience on the part of the vendor. The model represents the uncertainty and fluidity of the bidding process through the concept of bidding power. Newly competitive firms will tend to underbid a mature company (both on price and lead time), in part to gain a foothold in the market and in part from inexperience. The more newly competitive firms in the industry, the higher their bidding power; in other words, the more likely a given AS/RS proposal will be underbid. The proportion of contracts that mature firms lose to new firms rises with the bidding power of new competition.

#### New Competition Subsystem

The competitive subsystem models the startup, formation, maturing, and failure of new firms in the AS/RS industry and their competitive bidding behavior. Startup of new competition represents a firm's decision to enter the AS/RS industry and may correspond to the creation of an entirely new enterprise or to the revival of a company that has previously been active in the industry but has been lying dormant for a number of years. Despite the technological sophistication of the AS/RS equipment, executives in the industry feel the barriers to entry are quite low. Many firms in the aerospace and aircraft industry have the combination of engineering talents required for design and manufacture of automated material handling equipment, and the financial resources to support a new venture in a promising industry.

The decision to start a new venture is somewhat speculative. Entrepreneurs may be attracted to the industry by the example of colleagues who have already formed companies or by rumors of the potential growth in factory automation. There is, however, no reason to suppose that the plans of entrepreneurs are laid with full knowledge of future market size or existing industry capacity. The "invisible hand" that balances the capacity of the fledgling industry with its market is at best imprecise. In figure 3, startup of new competition depends on the capacity of new and mature firms. The more capacity, the more visible the fledgling industry, and the more likely it is to attract entrepreneurs and investors. This speculative startup process is regulated by the realities of business failure. Knowledge of failed enterprises (of which there have been many during the past ten years) will deter the otherwise enthusiastic entrepreneur.

Startup of new firms eventually leads to an increase in new competition capacity, but only after a delay of about two years to account for the time to arrange financing, to assemble a capable design and manufacturing team, and to install the necessary plant and equipment. In figure 3, the level of competition in formation represents new capacity in the pipeline. It is significant (and realistic) that this level does not influence startup, even though many embryonic firms could eventually lead to excess industry capacity. Individual entrepreneurs are simply unable to know the combined effect on capacity of the plans of all other entrepreneurs.<sup>3</sup>



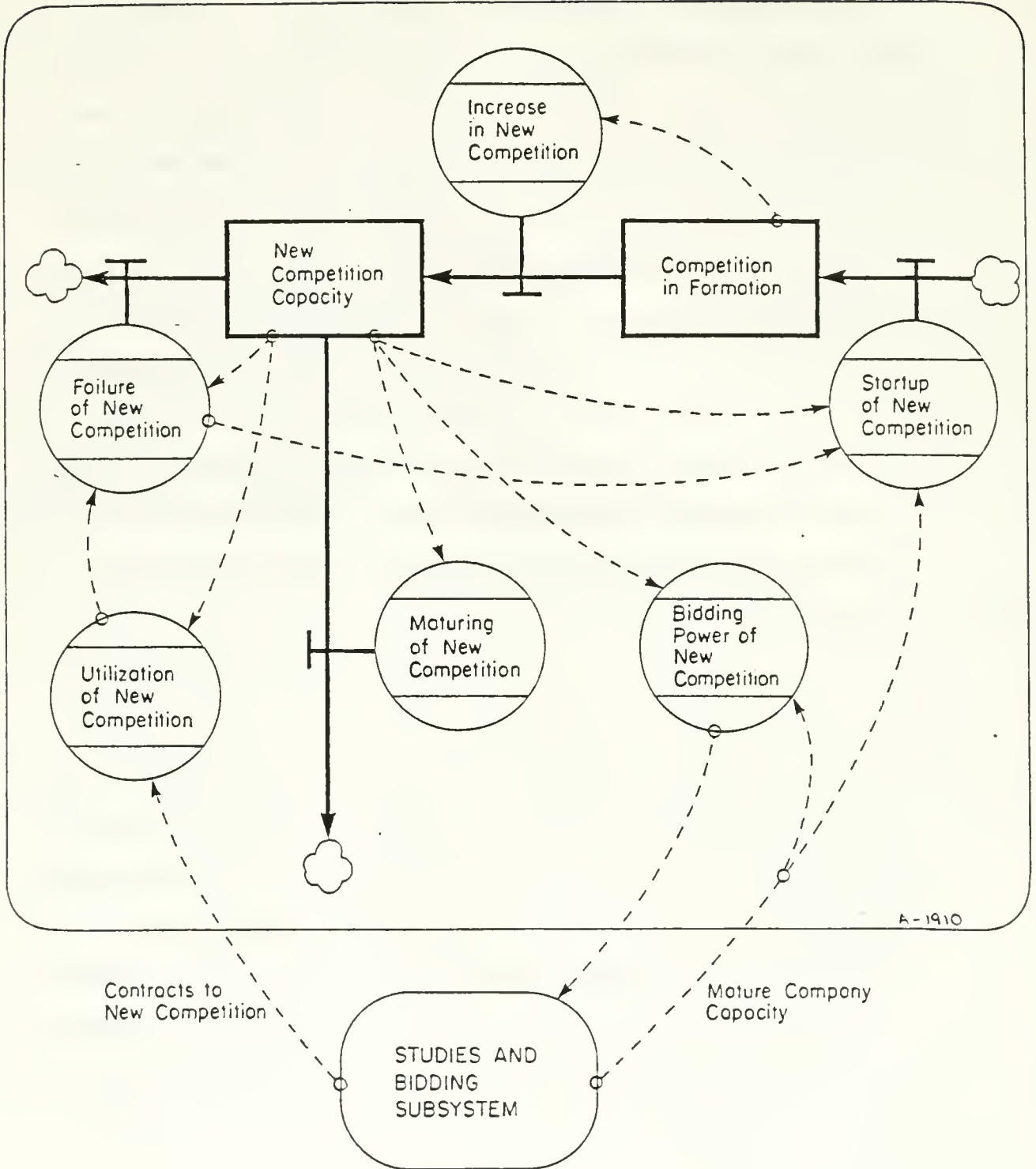


Figure 3. New Competition Subsystem



The competitive bidding behavior of new firms is captured in the concept of bidding power. It is assumed (based on informed executive opinion) that new firms underbid a mature firm on both price and lead time due to a combination of inexperience and desire to penetrate the market. The model computes bidding power as the ratio of new to mature capacity. As the proportion of new competition capacity rises in the industry, bidding power rises, reflecting an increase in the frequency of underbids.

New firm failure is a characteristic of the AS/RS business. Over fifty percent of the firms that have entered the industry in the last ten years have either failed or become dormant. In the model, failure is linked to capacity utilization. When utilization is low (meaning that new firms are winning too few contracts), the failure rate increases, thereby reducing industry capacity.

Successful firms eventually mature. As mature companies, they create an independent demand through promotion and studies and, therefore, are no longer a competitive threat from the perspective of an existing mature firm (the perspective of the model), particularly when the base of potential customers is large.

#### Marketing Subsystem

Marketing in the AS/RS industry means supplying information to the customer about the new technology and its advantages over conventional material handling methods. The task is carried out by the sales force. The

marketing subsystem models how the size of the sales force increases in a mature company. (Since the subsystem is quite simple, no diagram is provided.) The sales force is allocated a fixed percentage of revenues, proportional to the number of contracts won, in a standard incremental budgeting procedure. The budget determines the authorized sales force. Salesmen are hired to increase the actual sales force up to the authorized level.

#### SIMULATION ANALYSIS

Figure 4 shows the feedback loop structure of the behavioral simulation model just described.<sup>4</sup> We will use this figure to design and interpret simulation experiments of market dynamics in the fledgling AS/RS industry.<sup>5</sup>

#### Sustained Growth with Neutral Competition and Fixed Reputation

(Dynamics of the Real-Growth Loop)

Imagine that no competition exists in the AS/RS market. Suppose the market comprises a mature company selling to an unlimited base of customers. Although this scenario is not the real situation, it is helpful in building an understanding of market dynamics. How would such an idealized market evolve? Growth of AS/RS systems would be produced by the real-growth loop at the top of figure 4. Promotional effort by the sales force increases the number of customers interested in AS/RS technology. More customers request more studies, leading to more contracts and eventually to a larger budget for the salesforce. A larger sales force is able to expand the customer base further.

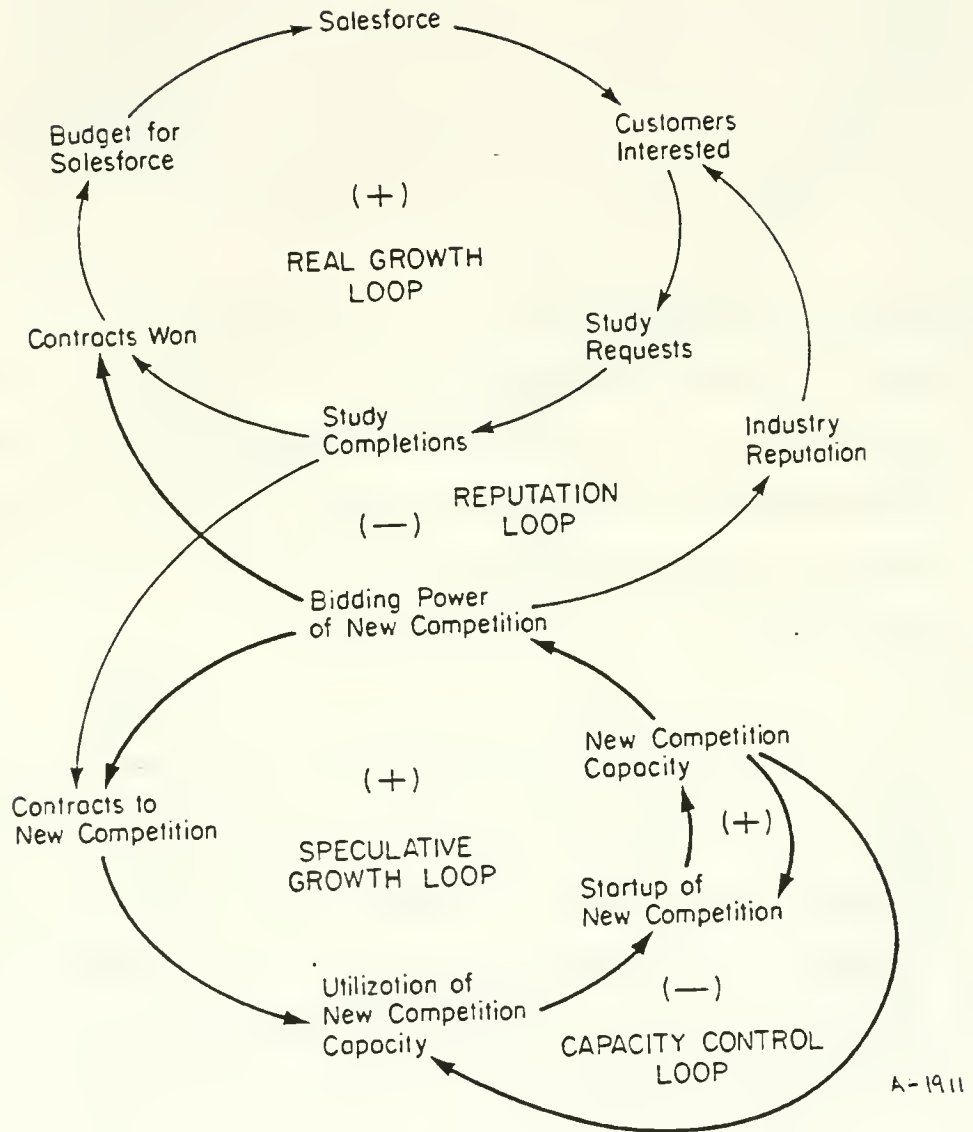


Figure 4. Feedback Loop Structure of the AS/RS Growth Market

Figure 5 shows the dynamic behavior of the isolated real-growth loop over twelve years. Initially there are 20 salesmen and 200 customers. The customers request 30 studies per year. Salesmen, customers, and study requests all grow exponentially at approximately 30% per year. Growth occurs because each additional salesman generates enough contracts to expand the sales budget by more than his expenses.

#### Slower Growth Resulting from Active Competition

Imagine now that newly competitive firms are active in the AS/RS market and are attracted to the industry according to the success or failure of existing companies. Imagine for the time being that the reputation of the industry is unaffected by the entry of new firms. How will the competitive market evolve?

Growth in demand for AS/RS systems is again produced by the real-growth loop of figure 4. Expansion of newly competitive firms is generated by the speculative-growth and capacity-control loops of figure 4. An increase in study completions by mature companies results in an increase in contracts going to new competition. More contracts raise the capacity utilization of new firms, thereby creating an attractive environment for the startup of firms. Startups lead eventually, after planning and logistical delays of about two years, to expansion of new competition capacity. As more firms enter the industry, the bidding power of new competition rises, meaning that prices and lead times quoted by the new competition are underbid relative to mature firms. Contracts awarded to

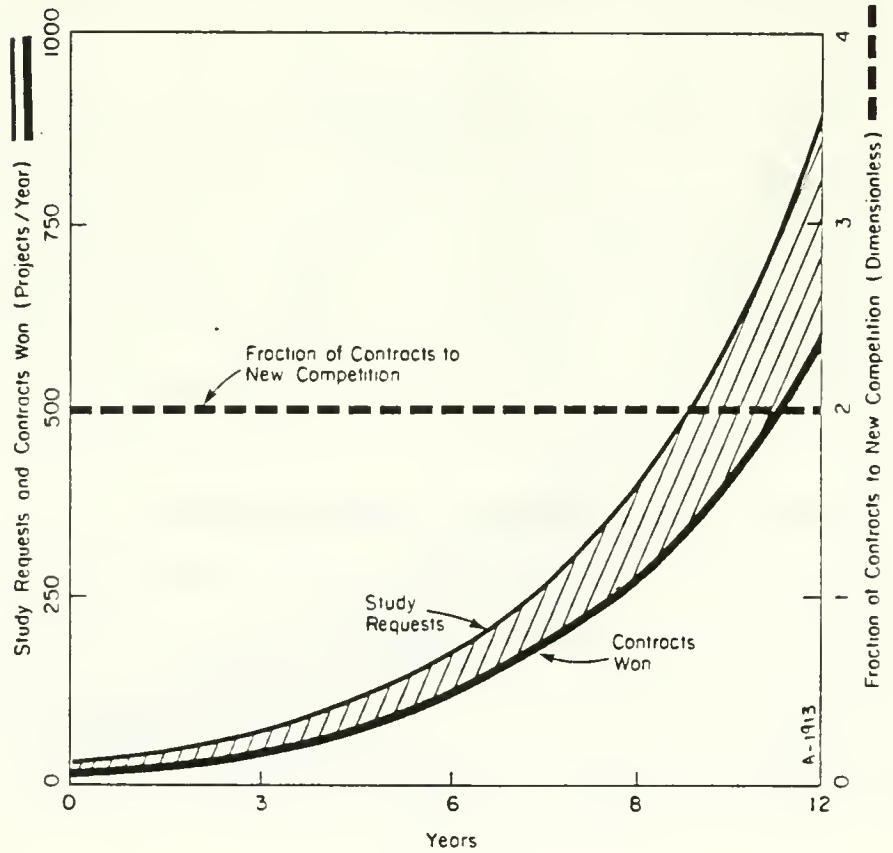
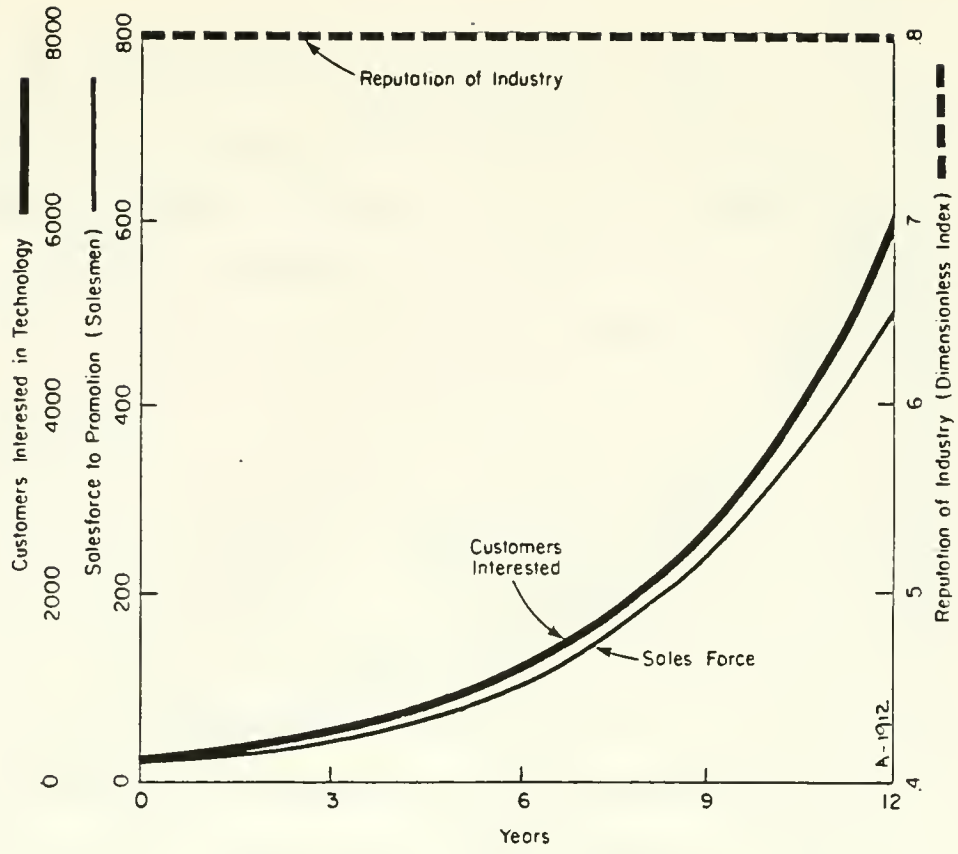


Figure 5. Sustained Growth with Neutral Competition and Fixed Reputation

the new competition therefore expand, setting in motion another round of new-firm startup and capacity expansion. Expansion is speculative. New firms do not increase the number of requests for AS/RS systems; they act as parasites on the demand created by mature firms.

Figure 6 shows the dynamic behavior of the combined real- and speculative-growth loops. There is sustained growth in customers, sales force, and study requests, similar to figure 5. Note, however, that the growth rate has been halved to approximately 15% per year in comparison with 30% in the previous scenario. Slower growth occurs because salesmen in the mature company produce less revenue, so the budget to fuel expansion is reduced. In effect, each salesman spends a portion of his time promoting the technology for the benefit of new competition.

New competition wins a greater share of contracts. As the AS/RS market grows, more new firms are attracted to the industry. The new firms underbid on price and lead time, thereby gaining market share. Figure 6 shows that new competition's share of contracts increases from 20% to more than 30% between years 3 and 6.

#### Dynamics of New Competition Capacity Expansion

Figure 7 shows that the capacity of new competition expands in three-year bursts of rapid growth punctuated by three-year periods of stagnation. At first sight, the behavior is rather strange. Why should capacity expand in bursts when demand (as represented by study requests) is growing at a

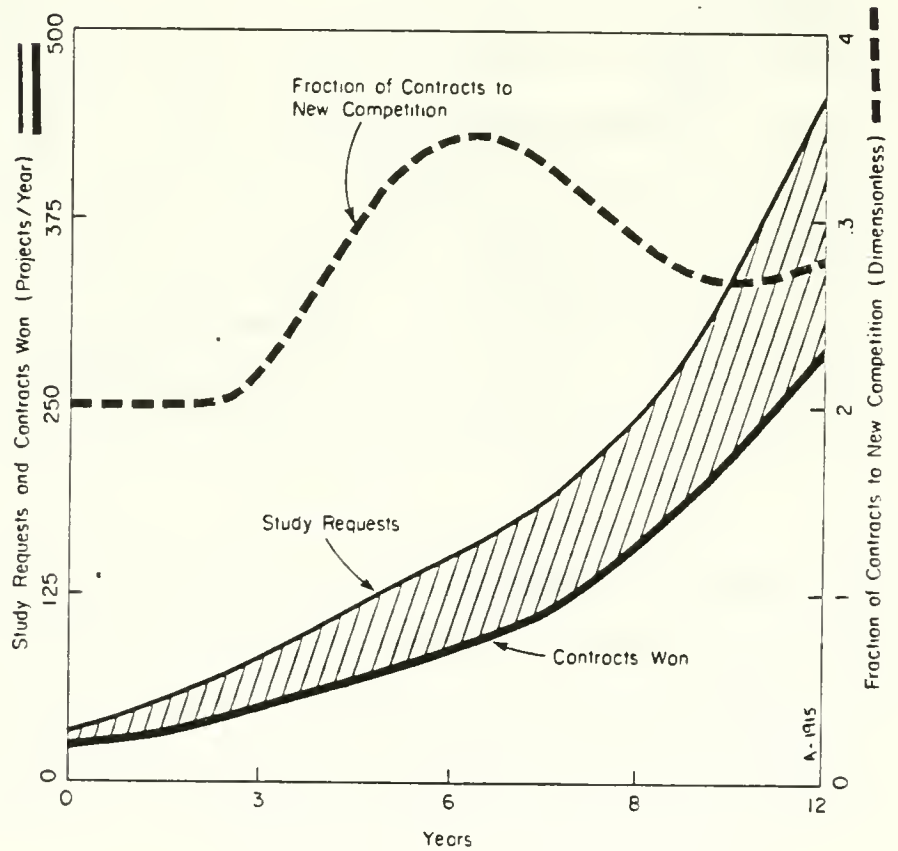
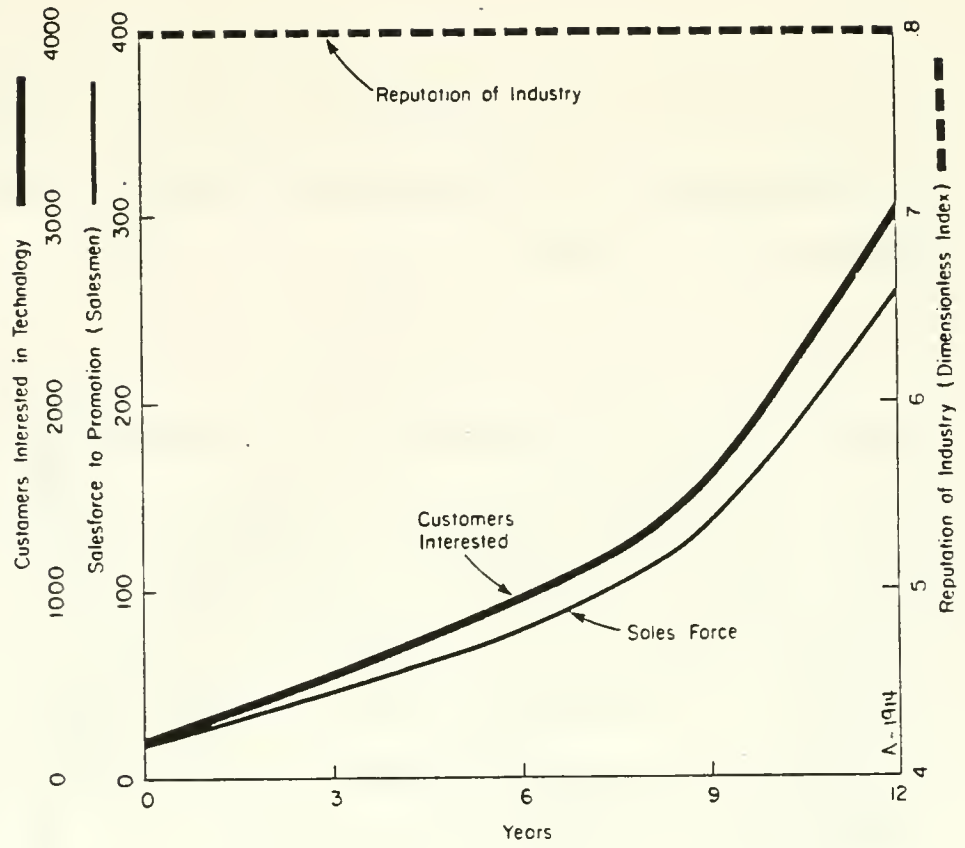


Figure 6. Slower Growth Resulting from Active Competition



uniform 15% annual rate? The simulation run provides an explanation by relating the behavior to assumptions about the policies and logistics governing new firm startup.

During the first two years of the run (up to time  $t_1$ ), growth in study requests results in more contracts for new competition and therefore growing utilization of capacity. Conditions are increasingly favorable for new firm startup. But entrepreneurs take time to perceive the favorable conditions and still more time to organize a new venture. As a consequence, new competition in formation lags more than two years behind the incentive for expansion. At time  $t_2$  in the figure, new competition in formation peaks when utilization of capacity is low. There is a glut of capacity. New firms are committed to enter the market when there is already sufficient capacity available. New capacity continues to grow rapidly as committed capacity comes on line. The capacity glut keeps utilization low in the three-year period between  $t_2$  and  $t_3$  despite steady growth in study requests. Low utilization discourages new ventures and new competition in formation falls. At time  $t_3$  the capacity glut is over. The stage is set for another round of rapid competitive growth. Utilization increases and new competition in formation surges upward.

#### Slow Growth and Stagnation Resulting from Variable Reputation

Now suppose that new firms lower the reputation of the AS/RS industry by, for example, unintentionally overselling their product to obtain a foothold in the market. In figure 4, industry reputation falls as the bidding power



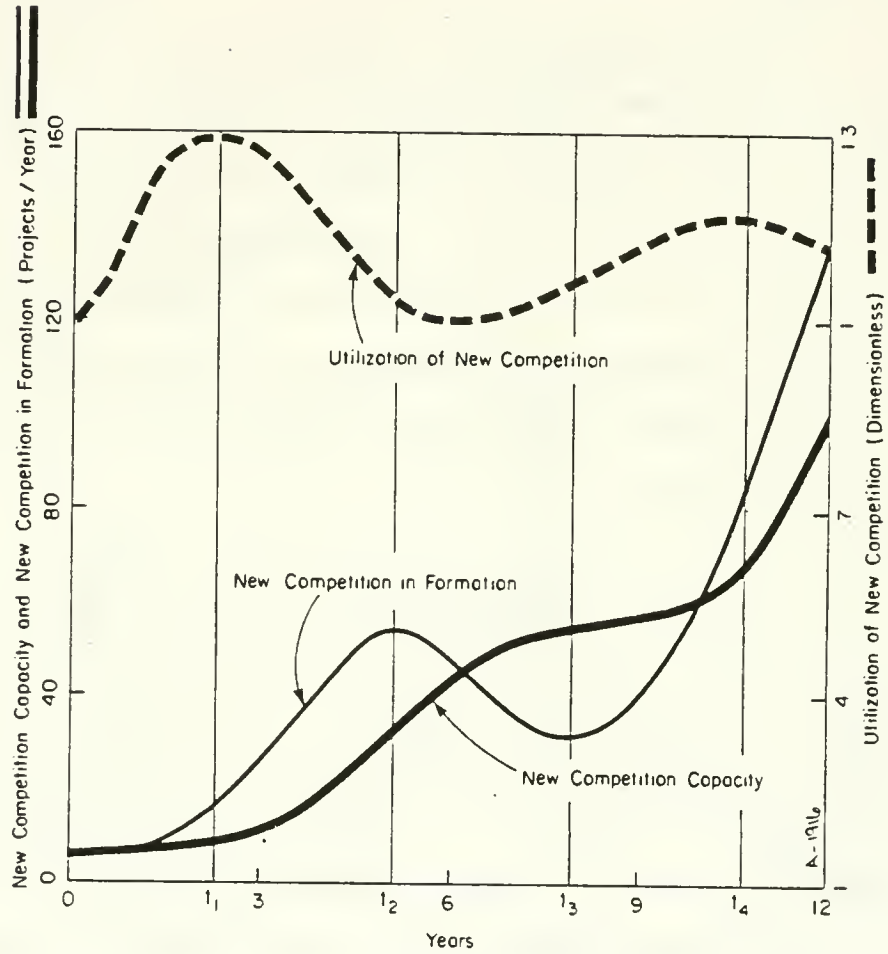


Figure 7. Dynamics of New Competition Capacity Expansion

of new competition rises. Low industry reputation reduces the number of customers interested in AS/RS technology and also lowers the proportion of customers requesting a study. The new connections link the speculative capacity expansion policies of new firms to the growth of demand.

Figure 8 is a simulation of the entire model, comprising the real-growth, speculative-growth, and reputation loops. By comparison with figure 6 (fixed reputation), growth is slowed. Moreover, in the interval between years 5 and 9 there is stagnation in customers and study requests that could readily be interpreted as saturation of the fledgling market. In fact, the stagnation is temporary. Starting in year 9, rapid growth of the market resumes. How is this fluctuating pattern of growth and diffusion produced?

At the start of the run, industry reputation is high, implying that new competition has only a small market presence. The mature company generates a healthy 20% annual growth in customers and study requests. This growth attracts a speculative surge of new firms which, in the interval between years 3 and 6, expand their share of contracts from 20% to almost 35%. As the proportion of new and inexperienced firms grows, industry reputation declines. Customers and study requests stagnate in the hostile and disenchanting market. The hiatus is not overcome until year 9, when the glut of new firms has been relieved by a shakeout, thereby reducing the market visibility of new competition and restoring industry reputation. The stage is set for another surge of growth. Customers,

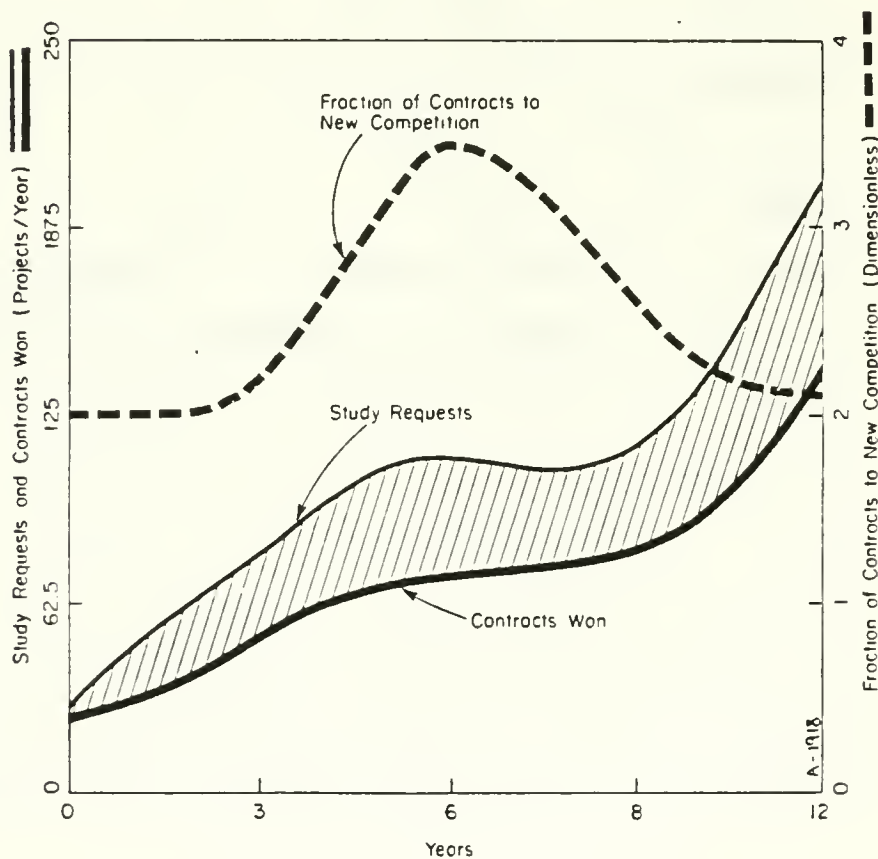
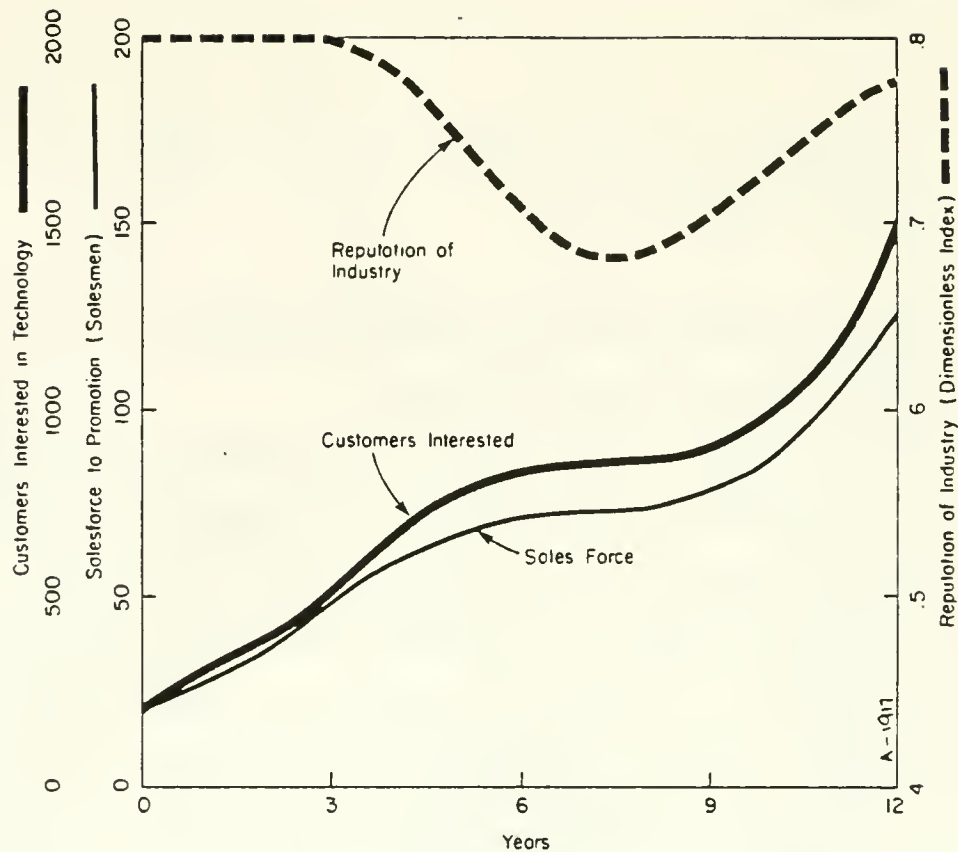


Figure 8. Slow Growth and Stagnation Resulting from Variable Reputation

sales force, and study requests grow at an annual rate of greater than 20% between years 9 and 12.

### Glut and Overshoot in New Competition Capacity

#### Resulting from Variable Reputation

With variable industry reputation, new competition produces a more serious glut of capacity and experiences wider variations in capacity utilization than in the case when reputation was held fixed. Figure 9 shows the simulated behavior of new competition. The causes of overexpansion of capacity are the same as discussed in the interpretation of figure 7. However, overexpansion is more pronounced because committed capacity comes on line at a time when demand for AS/RS equipment is stifled by the low reputation of the industry. The result is a growth cycle in new competition capacity with a period of about nine years.

#### INSIGHTS FROM THE MODEL

The model shows that in a fledgling market, which attracts aggressive and inexperienced competition, a long-term cycle (8-9 years) of growth and stagnation can readily be generated. The cycle is entirely independent of economic conditions and is the result of the structure of the market itself. The root cause of the cycle is the aggressive and speculative startup of new firms in response to market growth. New competition tends to overexpand when faced with a perceived market opportunity. As new firms gain market share, they dilute the marketing efforts of the industry by failing to assume the burden of promotion. Mature firms get a smaller

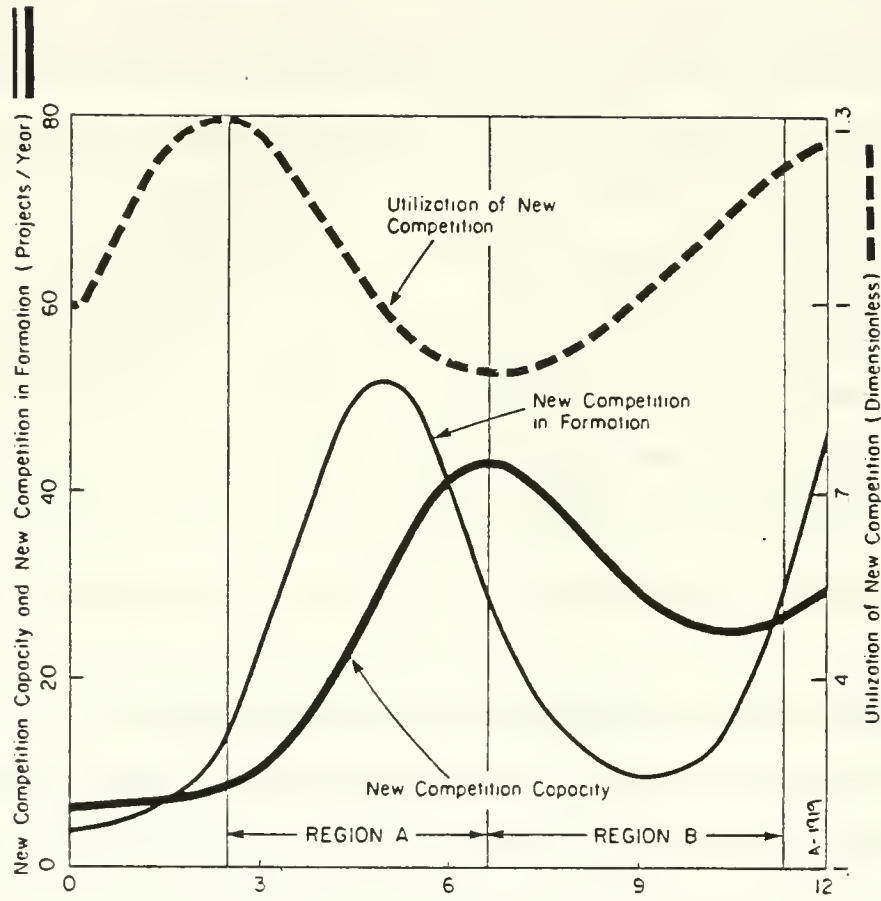


Figure 9. Glut and Overshoot in New Competition Capacity

return on their promotional investment, and market growth is retarded. Moreover, the inexperience of new firms depresses industry reputation, causing growth to stagnate until the least effective new firms are shaken out, thereby setting the stage for a new phase of market growth.

The dynamics of the fledgling market can readily confuse a mature company's assessment of long-run market potential. Referring to figure 8, the number of customers interested in the technology stagnates in year 6 after a period of sustained growth. No further growth occurs until year 9. Three years of stagnation might easily be interpreted as a sign of market saturation, particularly for a new technology, whose benefits over old technology (at least in the mind of the customer) are regarded as marginal. By assuming saturation, a mature company can fail to invest in capacity and engineering talent in readiness for the next phase of growth.

#### MARKETING POLICY CHANGE--ADOPTING A LEADERSHIP ROLE

The model was used to design a new marketing policy to stabilize the growth cycles, increase market growth rate, and improve financial performance. To address the financial implications of policy change the model was extended to include the cost structure and production/manpower planning policies of a typical mature firm (Morecroft and Homer 1980).

The new policy calls for leadership in marketing. A mature company should be prepared to expand marketing effort during long periods of market stagnation while excess competitive capacity is worked off and industry

reputation recovers. The policy anticipates that increased sales by new firms will temporarily damage industry reputation, thereby requiring offsetting promotional effort to sustain customer interest. The idea of expanding marketing effort to counter competitive growth may seem obvious. However, the model shows that to be effective such increased effort must be sustained for two or three years in the face of adverse conditions of declining market share and stagnating sales.

The leadership policy was modeled by increasing the percentage of revenues allocated to sales whenever the market share of newly competitive firms was expanding. The full market/firm model was simulated for a period of 15 years, first using the base marketing policy that allocates a fixed percentage of revenues to sales and then the new leadership policy. Table 1 shows the relative performance of the two policies. During the first five simulated years the policies perform very similarly. Both yield approximately the same accumulated revenue and net income (ratios equal to 1) and have almost the same average return on sales. The result is not surprising when we recall from figures 8 and 9 that new competition is rather inert at the start of the simulation, not expanding capacity or driving down industry reputation. A big difference in financial performance occurs between years 5 and 10, when new competition is growing quickly and industry reputation is falling. Accumulated revenue is increased by 40% under the leadership policy (revenue ratio of 1.4), and accumulated income is almost 3 times greater (income ratio of 2.7). Average return on sales is also 2% higher. The leadership policy achieves



Indicator	Time Interval (Years)		
	0-5	5-10	10-15
Ratio of Accumulated Net Income (Leadership/Base)	1.0	2.7	1.1
Ratio of Accumulated Revenue (Leadership/Base)	1.0	1.4	1.2
Difference in Average Return on Sales (Leadership - Base)	-.1%	2.0%	-.8%

Table 1. Relative Financial Performance  
of Leadership to Base Marketing  
Policies



these advantages by stimulating customer interest to offset the loss of interest caused by low industry reputation. The improvement in financial performance is less marked between years 10 and 15. During this period, industry reputation is high following a shakeout of new competition. As a result it is easier to build and maintain customer interest, so there is less need to stimulate the market aggressively.

#### CONCLUSION--GENERALIZING THE MODEL

The AS/RS market model has identified new feedback structures that are capable of explaining temporary setbacks in market growth and capacity expansion in emerging industries. It is useful to reflect on the model's assumptions and structures to understand the industrial situations in which it might apply.

The model looks at an industry where the sale of a product is an expensive and time-consuming task, and where part of the selling time is spent explaining the technology to the customer. Typically, such a product would be technically complex and expensive. Once the customer is informed of the technology, he may choose to buy the product from a competitor. Large computer systems, communication and switching systems, and factory automation systems may all fit this description.

Competitors in the industry are segmented into "professionals" and "speculators." Professionals are promoting the technology (through active marketing), are experienced, and are building high-quality products.

Speculators are riding piggyback on growing demand (expending less effort on marketing) and may build inferior products. Speculators are attracted to the industry by its growth potential and by the perceived success of other entering companies. There are many new competitors so that total industry capacity (installed and on line) is difficult to gauge in relation to demand.

The model shows that an industry with these marketing and competitive characteristics is prone to growth cycles--4- to 5-year periods of growth followed by 3- to 4-year periods of stagnation. This behavior results from a positive speculative growth loop that brings many new competitors into the industry following any upturn in demand. Speculative growth is only weakly checked by a negative loop balancing industry capacity and demand, so that excess capacity can readily occur. The speculators do not market the technology as vigorously as the "professionals" and, moreover, cause industry reputation to decline, thereby damping growth.

The model shows that the means for achieving smooth and rapid growth in such an industry lie in the hands of the professional firms. They must avoid being trapped into stagnation by the mistaken belief that slow growth is resulting from market saturation. Instead they must have a flexible planning system that allows a substantial and sustained increase in marketing budget during periods of new competitor growth.

## FOOTNOTES

1. For the reader who is unfamiliar with system dynamics flow diagramming symbols, a brief interpretation is provided below. For further information, refer to Forrester [1961, 81-85] and Morecroft (1982). In figure 1 the circular symbols represent decisionmaking processes or judgments, in this case, of the customers. The dotted lines represent the flows of information on which decisions or judgments are based. The rectangular symbol is a level representing an accumulation, in this case, customers interested in the technology. The solid lines represent flows adding to or subtracting from the level. The valve symbol indicates that a flow is regulated by the decisionmaking process to which the valve is attached. The cloudlike symbols represent the source and sink of physical flows, in this case, the pool of customers who might potentially be informed of AS/RS technology.
  
2. It is assumed (and true as a first approximation) that bidding competition among mature companies is much less than the bidding competition among new firms and the mature company that undertook the AS/RS feasibility study. Typically, mature companies are most interested in winning the contracts resulting from their own feasibility studies. New firms, who are trying to establish a foothold in the market, will bid aggressively on any contract offered.
  
3. The myopic capacity expansion plans of many firms in the same industry has been noted by Rothermel (1982).

4. See Richardson and Pugh (1981, 25-30) for further discussion of causal-loop diagrams.
  
5. The style of simulation analysis, using partial model tests and qualitative patterns of behavior, is intended to aid intuition and clarify the reasons for surprise (nonintuitive) behavior. This style of analysis is discussed further in Morecroft (Jan. 1984) and (Fall 1984) and is related to the dialectic inquiry method of Mason (1969) and Mitroff et al. (1982).

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TECHNICAL APPENDIX

Documentor Listing of the AS/RS Growth Model

PAGE 1 FILE GMASRSB GROWTH MODEL FOR AS/RS MARKET 7/19/83

GMASRS IS USED IN THE PAPER DYNAMICS OF A FLEDGLING  
HIGH TECHNOLOGY GROWTH MARKET

REVISED BY JOHN D.W. MORECROFT JULY 1983

THE MARKET SECTOR IS DIVIDED INTO FOUR SUBSYSTEMS  
1). INTEREST AND REPUTATION 2). STUDY AND CONTRACT  
3). NEW COMPETITION 4). MARKETING  
INTEREST AND REPUTATION SUBSYSTEM

CIT.K=CIT.J+(DT)(IC.JK-RC.JK-SR.JK) 2, L  
CIT=SR/(SRF\*MRSR) 2.1, N  
CIT - CUSTOMERS INTERESTED IN TECHNOLOGY  
(CUSTOMERS)  
DT - COMPUTATION INTERVAL OF SIMULATION (YEARS)  
IC - INCREASE IN CUSTOMERS (CUSTOMERS/YEAR)  
RC - REDUCTION OF CUSTOMERS (CUSTOMERS/YEAR)  
SR - STUDY REQUESTS (STUDIES/YEAR)  
SRF - STUDY REQUEST FRACTION (STUDIES/CUSTOMER-  
YEAR)  
MRSR - MULTIPLIER FROM REPUTATION ON STUDY  
REQUESTS (DIMENSIONLESS)

IC.KL=SFP.K\*CRSF 3, R  
CRSF=20 3.1, C  
IC - INCREASE IN CUSTOMERS (CUSTOMERS/YEAR)  
SFP - SALES FORCE TO PROMOTION (SALESMEN)  
CRSF - CONTACT RATE OF SALESFORCE (CUSTOMERS/  
SALESMAN-YEAR)

RC.KL=CIT.K/DI.K 4, R  
RC - REDUCTION OF CUSTOMERS (CUSTOMERS/YEAR)  
CIT - CUSTOMERS INTERESTED IN TECHNOLOGY  
(CUSTOMERS)  
DI - DURATION OF INTEREST (YEARS)

DI.K=NDI\*MRDI.K 5, A  
NDI=1 5.1, C  
DI - DURATION OF INTEREST (YEARS)  
NDI - NORMAL DURATION OF INTEREST (YEARS)  
MRDI - MULTIPLIER FROM REPUTATION ON DURATION OF  
INTEREST (DIMENSIONLESS)

MRDI.K=TABHL(TMRDI,ERI.K,0,1,.2) 6, A  
TMRDI=.3/.35/.45/.55/.75/1 6.1, T  
MRDI - MULTIPLIER FROM REPUTATION ON DURATION OF  
INTEREST (DIMENSIONLESS)  
TMRDI - TABLE FOR MRDI  
ERI - ESTABLISHED REPUTATION OF INDUSTRY  
(DIMENSIONLESS)



$ERI.K = ERI.J + (DT/TERI)(IRI.J - ERI.J)$  7, L  
 $ERI = IRI$  7.1, N  
 $TERI = 1.5$  7.2, C

ERI - ESTABLISHED REPUTATION OF INDUSTRY  
 (DIMENSIONLESS)  
 DT - COMPUTATION INTERVAL OF SIMULATION (YEARS)  
 TERI - TIME TO ESTABLISH REPUTATION OF INDUSTRY  
 (YEARS)  
 IRI - INDICATED REPUTATION OF INDUSTRY  
 (DIMENSIONLESS)

$IRI.K = (1 - FCNC.K) * SWRI + (1 - SWRI) * (4/5)$  8, A  
 $SWRI = 1$  8.1, C

IRI - INDICATED REPUTATION OF INDUSTRY  
 (DIMENSIONLESS)  
 FCNC - FRACTION OF CONTRACTS TO NEW COMPETITION  
 (DIMENSIONLESS)  
 SWRI - SWITCH FOR REPUTATION OF INDUSTRY  
 (DIMENSIONLESS)

$SR.KL = CIT.K * SRF * MRSR.K$  9, R  
 $SR = 30$  9.1, N  
 $SRF = .2$  9.2, C

SR - STUDY REQUESTS (STUDIES/YEAR)  
 CIT - CUSTOMERS INTERESTED IN TECHNOLOGY  
 (CUSTOMERS)  
 SRF - STUDY REQUEST FRACTION (STUDIES/CUSTOMER-  
 YEAR)  
 MRSR - MULTIPLIER FROM REPUTATION ON STUDY  
 REQUESTS (DIMENSIONLESS)

$MRSR.K = TABLE(TMRSR, ERI.K, 0, 1, .2)$  10, A  
 $TMRSR = .3/.35/.45/.55/.75/1$  10.1, T

MRSR - MULTIPLIER FROM REPUTATION ON STUDY  
 REQUESTS (DIMENSIONLESS)  
 TMRSR - TABLE FOR MRSR  
 ERI - ESTABLISHED REPUTATION OF INDUSTRY  
 (DIMENSIONLESS)

#### STUDY AND BIDDING SUBSYSTEM

$PS.K = PS.J + (DT)(SS.JK - CLNC.JK - CW.JK)$  11, L  
 $PS = NTS * SR$  11.1, N

PS - PROJECTS UNDER STUDY (PROJECTS)  
 DT - COMPUTATION INTERVAL OF SIMULATION (YEARS)  
 SS - STUDY STARTS (PROJECTS/YEAR)  
 CLNC - CONTRACTS LOST TO NEW COMPETITION  
 (PROJECTS/YEAR)  
 CW - CONTRACTS WON (PROJECTS/YEAR)  
 NTS - NORMAL TIME PER STUDY (YEARS)  
 SR - STUDY REQUESTS (STUDIES/YEAR)

$SS.KL = SR.JK$  12, R

SS - STUDY STARTS (PROJECTS/YEAR)  
 SR - STUDY REQUESTS (STUDIES/YEAR)

$CLNC.KL=SC.K*FCNC.K$  13, R

CLNC - CONTRACTS LOST TO NEW COMPETITION  
(PROJECTS/YEAR)

SC - STUDY COMPLETIONS (PROJECTS/YEAR)

FCNC - FRACTION OF CONTRACTS TO NEW COMPETITION  
(DIMENSIONLESS)

$CW.KL=SC.K*(1-FCNC.K)$  14, R

CW - CONTRACTS WON (PROJECTS/YEAR)

SC - STUDY COMPLETIONS (PROJECTS/YEAR)

FCNC - FRACTION OF CONTRACTS TO NEW COMPETITION  
(DIMENSIONLESS)

$SC.K=PS.K/NTS$  15, A

$NTS=.5$  15.1, C

SC - STUDY COMPLETIONS (PROJECTS/YEAR)

PS - PROJECTS UNDER STUDY (PROJECTS)

NTS - NORMAL TIME PER STUDY (YEARS)

$FCNC.K=TABLE(TFCNC,BFNC.K,0,1.6,.2)$  16, A

$TFCNC=0/.2/.35/.45/.52/.6/.68/.72/.76$  16.1, T

FCNC - FRACTION OF CONTRACTS TO NEW COMPETITION  
(DIMENSIONLESS)

TFCNC - TABLE FOR FCNC

BFNC - BIDDING POWER OF NEW COMPETITION  
(DIMENSIONLESS)

$BFNC.K=(NCC.K/(MCC.K+NCC.K))*SWNC+(1-SWNC)*1/5$  17, A

$SWNC=1$  17.1, C

BFNC - BIDDING POWER OF NEW COMPETITION  
(DIMENSIONLESS)

NCC - NEW COMPETITION CAPACITY (PROJECTS/YEAR)

MCC - MATURE COMPANY CAPACITY (PROJECTS/YEAR)

SWNC - SWITCH FOR NEW COMPETITION (DIMENSIONLESS)

#### NEW COMPETITION SUBSYSTEM

$NCC.K=NCC.J+(DT)(INC.JK-FNC.JK-MNC.JK)$  18, L

$NCC=NNCC$  18.1, N

$NNCC=6$  18.2, C

NCC - NEW COMPETITION CAPACITY (PROJECTS/YEAR)

DT - COMPUTATION INTERVAL OF SIMULATION (YEARS)

INC - INCREASE IN NEW COMPETITION (PROJECTS/YEAR/  
YEAR)

FNC - FAILURE OF NEW COMPETITION (PROJECTS/YEAR/  
YEAR)

MNC - MATURING OF NEW COMPETITION (PROJECTS/YEAR/  
YEAR)

NNCC - INITIAL NEW COMPETITION CAPACITY (PROJECTS/  
YEAR)

$FNC.KL = NCC.K * FR * MUF.K$  19, R  
 $FR = .25$  19.1, C  
 FNC - FAILURE OF NEW COMPETITION (PROJECTS/YEAR/  
 YEAR)  
 NCC - NEW COMPETITION CAPACITY (PROJECTS/YEAR)  
 FR - FAILURE RATE (FRACTION/YEAR)  
 MUF - MULTIPLIER FROM UTILIZATION ON FAILURE  
 (DIMENSIONLESS)

$MUF.K = TABLE(TMUF, UNC.K, .6, 1.4, .2)$  20, A  
 $TMUF = 4/2.2/1/.25/0$  20.1, T  
 MUF - MULTIPLIER FROM UTILIZATION ON FAILURE  
 (DIMENSIONLESS)  
 TMUF - TABLE FOR MUF  
 UNC - UTILIZATION OF NEW COMPETITION  
 (DIMENSIONLESS)

$UNC.K = CLNC.JK / NCC.K$  21, A  
 UNC - UTILIZATION OF NEW COMPETITION  
 (DIMENSIONLESS)  
 CLNC - CONTRACTS LOST TO NEW COMPETITION  
 (PROJECTS/YEAR)  
 NCC - NEW COMPETITION CAPACITY (PROJECTS/YEAR)

$MNC.KL = NCC.K * MR$  22, R  
 $MR = .11$  22.1, C  
 MNC - MATURING OF NEW COMPETITION (PROJECTS/YEAR/  
 YEAR)  
 NCC - NEW COMPETITION CAPACITY (PROJECTS/YEAR)  
 MR - MATURING RATE (FRACTION/YEAR)

$INC.KL = DELAY3(SNC.JK, TENC)$  23, R  
 $TENC = 2$  23.1, C  
 INC - INCREASE IN NEW COMPETITION (PROJECTS/YEAR/  
 YEAR)  
 SNC - STARTUP OF NEW COMPETITION (PROJECTS/YEAR/  
 YEAR)  
 TENC - TIME TO ESTABLISH NEW COMPETITION (YEARS)

$NCF.K = NCF.J + (DT)(SNC.JK - INC.JK)$  24, L  
 $NCF = SC * STR * TENC$  24.1, N  
 NCF - NEW COMPETITION IN FORMATION (PROJECTS/  
 YEAR)  
 DT - COMPUTATION INTERVAL OF SIMULATION (YEARS)  
 SNC - STARTUP OF NEW COMPETITION (PROJECTS/YEAR/  
 YEAR)  
 INC - INCREASE IN NEW COMPETITION (PROJECTS/YEAR/  
 YEAR)  
 SC - STUDY COMPLETIONS (PROJECTS/YEAR)  
 STR - STARTUP RATE (FRACTION/YEAR)  
 TENC - TIME TO ESTABLISH NEW COMPETITION (YEARS)

$SNC.KL = (NCC.K + MCC.K) * STR * MFS.K$  25, R  
 $STR = .072$  25.1, C  
 SNC - STARTUP OF NEW COMPETITION (PROJECTS/YEAR/  
 YEAR)  
 NCC - NEW COMPETITION CAPACITY (PROJECTS/YEAR)  
 MCC - MATURE COMPANY CAPACITY (PROJECTS/YEAR)  
 STR - STARTUP RATE (FRACTION/YEAR)  
 MFS - MULTIPLIER FROM FAILURE ON STARTUP  
 (DIMENSIONLESS)

$MCC.K = DELAY1(CW.JK, TAC)$  26, A  
 $MCC = SR - NNCC$  26.1, N  
 $TAC = 1.5$  26.2, C  
 MCC - MATURE COMPANY CAPACITY (PROJECTS/YEAR)  
 CW - CONTRACTS WON (PROJECTS/YEAR)  
 TAC - TIME TO ADJUST CAPACITY (YEARS)  
 SR - STUDY REQUESTS (STUDIES/YEAR)  
 NNCC - INITIAL NEW COMPETITION CAPACITY (PROJECTS/  
 YEAR)

$MFS.K = TABLE(TMFS, PFR.K, 0, 4, .5)$  27, A  
 $TMFS = 10/4/1/.5/.3/.2/.1/.1/.1$  27.1, T  
 MFS - MULTIPLIER FROM FAILURE ON STARTUP  
 (DIMENSIONLESS)  
 TMFS - TABLE FOR MFS  
 PFR - PERCEIVED FAILURE RATE (PROJECTS/YEAR/YEAR)

$PFR.K = PFR.J + (DT/TPFR)(FRNC.J - PFR.J)$  28, L  
 $PFR = FRNC$  28.1, N  
 $TPFR = 1$  28.2, C  
 PFR - PERCEIVED FAILURE RATE (PROJECTS/YEAR/YEAR)  
 DT - COMPUTATION INTERVAL OF SIMULATION (YEARS)  
 TPFR - TIME TO PERCEIVE FAILURE RATE (YEARS)  
 FRNC - FAILURE RATIO FOR NEW COMPETITION  
 (DIMENSIONLESS)

$FRNC.K = MUF.K$  29, A  
 FRNC - FAILURE RATIO FOR NEW COMPETITION  
 (DIMENSIONLESS)  
 MUF - MULTIPLIER FROM UTILIZATION ON FAILURE  
 (DIMENSIONLESS)

#### MARKETING SUBSYSTEM

$SFF.K = SFF.J + (DT)(CSFF.JK)$  30, L  
 $SFF = (SR * (1 - FCNC) * PF * FBF) / SE$  30.1, N  
 SFF - SALES FORCE TO PROMOTION (SALESMEN)  
 DT - COMPUTATION INTERVAL OF SIMULATION (YEARS)  
 CSFF - CHANGE IN SALESFORCE TO PROMOTION  
 (SALESMEN/YEAR)  
 SR - STUDY REQUESTS (STUDIES/YEAR)  
 FCNC - FRACTION OF CONTRACTS TO NEW COMPETITION  
 (DIMENSIONLESS)  
 PF - PROJECT PRICE (DOLLARS/PROJECT)  
 FBF - FRACTION OF BUDGET TO PROMOTION  
 (DIMENSIONLESS)  
 SE - SALESFORCE EXPENSE (DOLLARS/SALESMAN-YEAR)

$CSFF.KL = ((ISFF.K - SFF.K) / TCSF) * SWSF$  31, R  
 $SWSF = 1$  31.1, C  
 $TCSF = .5$  31.2, C  
 CSFF - CHANGE IN SALESFORCE TO PROMOTION  
 (SALESMEN/YEAR)  
 ISFF - INDICATED SALES FORCE TO PROMOTION  
 (SALESMEN)  
 SFF - SALES FORCE TO PROMOTION (SALESMEN)  
 TCSF - TIME TO CORRECT SALES FORCE (YEARS)  
 SWSF - SWITCH FOR SALESFORCE (DIMENSIONLESS)

$ISFF.K = NBSF.K / SE$  32, A  
 $SE = 1.2E5$  32.1, C  
 ISFF - INDICATED SALES FORCE TO PROMOTION  
 (SALESMEN)  
 NBSF - NORMAL BUDGET FOR SALESFORCE (DOLLARS/YEAR)  
 SE - SALESFORCE EXPENSE (DOLLARS/SALESMAN-YEAR)

$NBSF.K = CW.JK * PP * FBP$  33, A  
 $PP = 4E6$  33.1, C  
 $FBP = .03$  33.2, C  
 NBSF - NORMAL BUDGET FOR SALESFORCE (DOLLARS/YEAR)  
 CW - CONTRACTS WON (PROJECTS/YEAR)  
 PP - PROJECT PRICE (DOLLARS/PROJECT)  
 FBP - FRACTION OF BUDGET TO PROMOTION  
 (DIMENSIONLESS)

## CONTROL STATEMENTS

$SPEC \ LENGTH = 0 / IT = .1 / PRTPER = 1 / PLTPER = .3$  33.6  
 LENGTH - LENGTH OF SIMULATION RUN (YEARS)  
 DT - COMPUTATION INTERVAL OF SIMULATION (YEARS)  
 PRTPER - PRINT PERIOD OF SIMULATION (YEARS)  
 PLTPER - PLOT PERIOD OF SIMULATION (YEARS)

$PRINT \ SR, CW, FCNC, SFF, NCC, NCF, UNC, ERI$  33.7  
 SR - STUDY REQUESTS (STUDIES/YEAR)  
 CW - CONTRACTS WON (PROJECTS/YEAR)  
 FCNC - FRACTION OF CONTRACTS TO NEW COMPETITION  
 (DIMENSIONLESS)  
 SFF - SALES FORCE TO PROMOTION (SALESMEN)  
 NCC - NEW COMPETITION CAPACITY (PROJECTS/YEAR)  
 NCF - NEW COMPETITION IN FORMATION (PROJECTS/  
 YEAR)  
 UNC - UTILIZATION OF NEW COMPETITION  
 (DIMENSIONLESS)  
 ERI - ESTABLISHED REPUTATION OF INDUSTRY  
 (DIMENSIONLESS)

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BASEMENT

