Managing and Understanding Technological Innovations

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Abstract

Controlling the development of new products, their growth and market penetration is a key task for corporate management. Its importance for the firm's survival triggered extensive mathematical modeling efforts to improve the decision making quality. Most models used in this field, however, lack crucial factors of success or failure of innovations; they frequently do not include managerial decision variables like price, delivery delays, quality, etc. or do not reflect comprehensively the involved factors.

The paper outlines the concepts of computer based Strategy Support and the role of Management Simulators. A modularly composed simulation model of the innovation process is presented which reflects the tight interrelationships between corporate actions and market response. It explains how the dynamics of a product life cycle are generated, and how structure causes behavior.

The model is relatively easy to understand in its elements and catches essential aspects of innovation dynamics. Its actual complexity results largely from the connectiveness of the variables and the nonlinear relations. Its applicability to managerial problem solving is demonstrated by analyzing and evaluating different strategies like pricing, capacity expansion and the role of effective quality control.

The model is extended to include the processes of Research and Development and their relationships to resource allocation and market success. A management simulator – based on the comprehensive innovation model – is introduced which supports teaching and training and fosters Organizational Learning.

Market Dynamics of New Products

A key framework in business management is the concept of a product life cycle. It usually describes the time pattern of a product through subsequent market stages like introduction, growth, maturity, and decline or - in a more comprehensive view - also includes the processes of R&D. Although this framework has its merits as a powerful heuristic, most models generating the cycle's characteristic logistic curve, do not reflect properly the factors causing its behavior. They do not catch the underlying structure. They are based upon biological or physical analogies, and fail to take sufficiently into account the economic environment of competition, capital investment, cost and price effects, etc. A comprehensive discussion of basic methodological differences between these perspectives is provided by Georgescu-Roegen (1971).

Purchasing decisions do not follow the same natural laws as do the spread of a disease or the dissipation of particles. Models which do not comprise the relevant decision variables exhibit a significant lack of policy content. They do not explain how structure causes behavior. They cannot indicate, how managerial action can promote but also impede innovation diffusion and adoption.

Only rarely touched in academic treatises (Linstone and Sahal 1976, Norton and Bass 1987), in reality, however, closely connected, is the transition of one innovation to other even more advanced and/or more attractive products. Most models show the diffusion, not the evolution of a phenomenon. They concentrate on – and thereby isolate – the short term dynamics of an innovation; they do not reflect the substitution processes between a sequence of products which take place as technology advances. Exactly these factors are to be considered and represented endogenously in a model if it is to be used as a meaningful tool for improving the effectiveness of managerial decision making.

Due to the dynamics of innovative markets, substitution between technologies can occur rather rapidly, leaving only little time for the firm to earn an adequate return on its investment. Figure 1 shows an example from the field of high technology: the sales and price development of subsequent generations of memory chips. Each new generation brought with it a quadrupling of respective capacity. Very short life cycles and a dramatic decay in prices characterize this market.

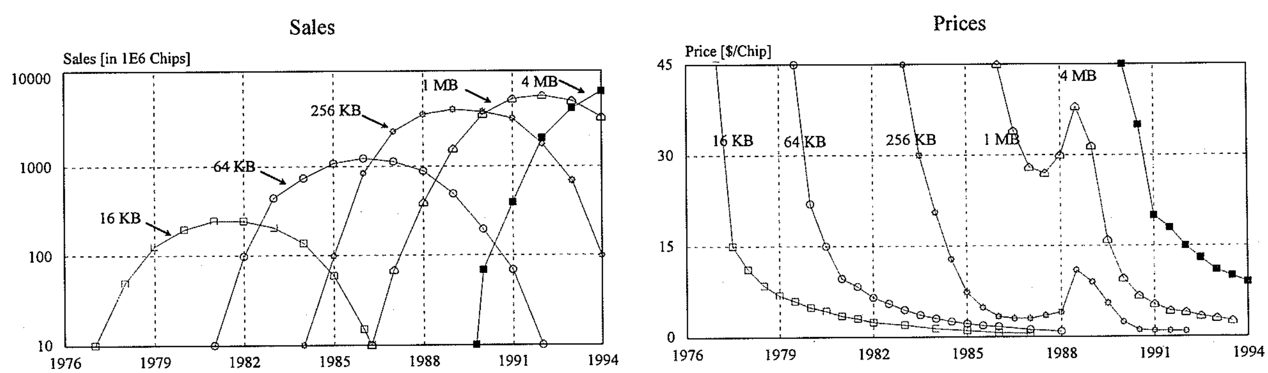

Fig. 1. Sales volume and price development of memory chips

The graphs indicate how vital it is for firms in this business to build up in time the required production capacity to assure immediate delivery when demand gains momentum. The sharp decline in prices shortens the period over which cash flow can be generated. It is only in the very early stages of the life cycle that high prices can be charged to compensate research and development expenditures; delivery delays lead to a permanent loss of revenues.

This behavior might suggest a strategy of high pricing together with an early investment in production capacity. This, however, also implies high fixed cost and consequently little flexibility if demand was overestimated or the market is already in its down-swing. Furthermore, such a policy may lead to slow market penetration, impeding the rate of diffusion, and reducing the benefits of large production volumes. Thus, due to the complexity of the system, the risks involved and the need for rational decision making, a formal strategy support system is required.

Strategy Support Systems in Innovation Management

The rate of innovation diffusion and the hazards of an early appearance of substituting products with an even higher level of technical sophistication are only partly determined by forces outside the corporation. They are also influenced by the behavior of the firm itself. The firm's actions produce or co-produce the pattern and the time frame of a product's market performance.

Firm and market, action and reaction are linked together in a feedback relationship. Managerial decisions are endogenous variables of the market system. They must be included in a model which is designed to serve as a decision support tool for management. From this feedback perspective, the aspects which cause success or failure of the corporation are to be represented.

Innovation management is a complex and highly dynamic task; it requires decisions, whose effectiveness is crucial for the firm's survival. It relies heavily on managerial judgment and experience. Decision making at this level of complexity cannot be automated, but it can be substantially supported by formalized models and computerized inquiring systems. It is this kind of managerial problem solving, where Strategy Support Systems (SSS) can successfully be applied. These systems link cognitive processes to computer routines and gain synergy from this combination. The expected benefits justify the substantial efforts required. Causal modeling and computer simulation allow insights into the behavior of systems. This approach combines theory based investigation and practical research of laboratory experiments and constitutes a third pillar for rational decision making.

Strategy Support Systems are concerned with the provision of computer assistance beyond the classical areas of programmed decision making; also for the ill-defined problems at the level of business policy making formal models are available and should be used. They stress the uphold, rather than the replacement, of managerial judgment; computer simulation should function as an „intelligence amplifier“ to stimulate creativity. And SSS aim at the effectiveness of decision making rather than its efficiency; decision support does not have to provide cheaper access to information or allow faster problem solving, instead it should lead to improved decision making, to a better understanding of objectives, and to more carefully investigated courses of action.

Strategy Support Systems utilize the tremendous developments in computer software and hardware. Within the same environment, different types of problems can be handled in a man-machine dialogue. Data are kept available, a collection of tools for the design, analysis and presentation of models allows their modular composition.

If management wants to play a major role in controlling the future course of the company – and not simply adjust to predetermined behavior modes –, it must have a thorough understanding of the system. A comprehensive and causal approach to model building is required. To achieve insights into the processes under investigation, the factors that cause system behavior must be represented. Models must explain and help to understand why specific behavior modes occur; they must explicitly link structure to behavior. Only then, they can be meaningful tools to improve managerial decision processes.

Insights into the dynamics of the system under investigation, not forecasts nor predictions, are the objective of such an endeavor. It is a paradigm of this systems approach that through the iterative processes of model design and simulation analysis the intrinsic properties of the problem will be better understood (de Geus 1988; Milling 1990b; Stata 1989).

Launching new products into the market is not a completely unique and unprecedented task, its process exhibits at least a certain amount of structure. A product – even an innovative one – is characterized by a rather limited number of general attributes like investment or consumption good, short versus long lived, high technology versus low technology, etc. These similarities together with the knowledge about generic model structure and behavior form the basis for interactive decision support.

Well designed models for numerical simulation allow an effective investigation of the problem situation. They contribute to an improved understanding of the dynamic interactions in a complex environment. Through such a kind of computer-based model development and model analysis, management can improve its perspective and understanding of reality. This will finally lead to more effective decision making.

A General Framework for Innovation Diffusion

In the following the coarse structure of a model generating the life cycle of a new product is presented and analyzed in its dynamic implications (Milling 1986a, b; Milling 1991a, b). The model is designed and evaluated on the basis of following assumptions:

(i) The dynamics of an innovation are initially studied without competition between individual firms. Although competition is not included at the micro level, it can and will occur between different levels of technology. Substitution will take place when a superior technology is introduced into the market. The product under consideration can be thought of as a technologically sophisticated consumer durable like micro wave ovens, video recorders, CD players, etc.

(ii) Production on stock – at least at a level significant for the analysis – is not feasible. When incoming orders stay below capacity, the level of output is reduced accordingly.

(iii) Basically, market acceptance of the innovation is assumed. The model serves as a simulator to determine how individual strategies can accelerate or hamper market penetration and profit performance. It is not its objective to predict market success or failure of an innovation.

Figure 2 shows the model's main components and transfer rates. The upper part focuses on the market level, the lower part on the level of the firm.

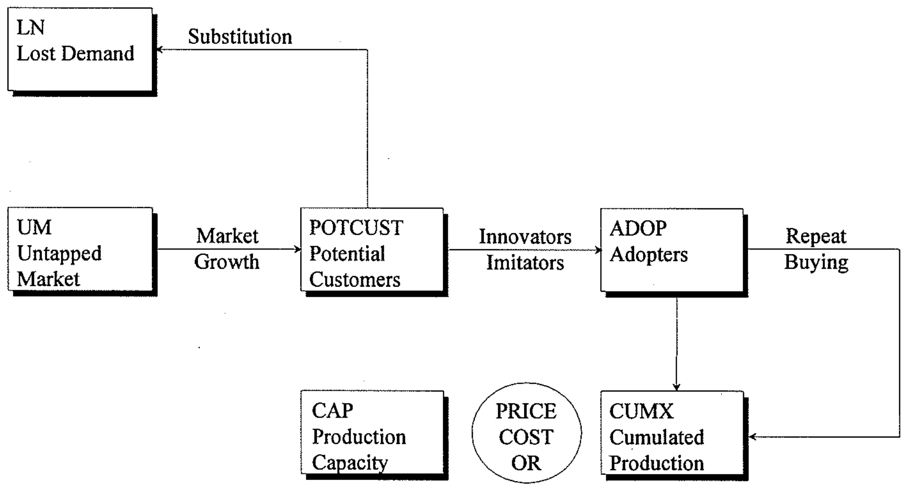

Fig. 2. Coarse structure of the innovation diffusion model

Potential Customers *(PC)* can be gained as buyers for the product under consideration. If the Potential Customers actually make the expected purchasing decision they turn into Adopters *(ADOP*). The variables *PC* and *ADOP* together with transfers in between are the key variables of innovation diffusion. The Untapped Market *(UM)* covers the latent demand which – due to the lack of information concerning the existence of a new product e. g. or because of too high prices or other economic reasons – has not been activated yet. Respective actions can lead to an increase in the number of Potential Customers. Besides the growth resulting from the influx from Untapped Market also a decline in market volume can be caused by the loss of Potential Customers. This Lost Demand *(LD)* turned to substituting products which are more attractive, e.g. on a higher level of technological sophistication.

The basic structure of the market penetration processes is derived from the classic deterministic epidemics model. Different buying categories in the process of innovation diffusion are distinguished. The members of each react differently with respect to the already achieved market penetration, prices charged, and product quality. This differentiation is a frequently found procedure in the innovation literature (e.g. Bass 1980). On this basis an innovation diffusion kernel was designed; it represents the state of the art of corporate innovation modeling. This core model is extended to include – among others – such aspects as cost performance, decisions on investment in production capacity and quality control.

In the first stage of the innovation process, „innovators“ take up the new product; this term refers to the type of customer who makes his purchasing decision uninfluenced in timing and the probability by the number of already existing adopters. The number of innovators is solely a function of the number of Potential Customers (Bass 1980, 1969). The decision of the group of innovators in each period to buy a new product D_{INNO} is defined as an „innovation coefficient“ p times the number of Potential Customers PC

$$D_{INNO}(t) = p \times PC(t) \qquad (1)$$

Innovators induce a second layer of Potential Customers to enter the market; these imitators have in some sense learned from those who have already adopted the good. Their volume depends upon the communication between Potential Customers and actual purchasers. Thus, new product growth is initiated by innovators but it gains its momentum from the communication between Potential Customers and the increasing level of Adopters. This communication approach is based upon the concepts of diffusion theory, which was used in numerous scientific disciplines to develop formal models of such processes (Pearl 1924, Bailey 1957, Mahajan and Muller 1979).

To model this behavior, the number of possible contacts between the members of this set has to be determined (Milling 1986a). If N is the total number of people, the amount of possible combinations C_N^k between them is

$$C_N^k = \binom{N}{k} = \frac{N!}{k!(N-k)!} \tag{2}$$

Here we are only interested in pairwise combinations (k = 2) between the elements in N

$$\begin{aligned} C_N^2 &= \binom{N}{2} = \frac{N!}{2!(N-2)!} \\ &= \frac{N(N-1)}{2!} = \frac{1}{2}(N^2 - N) \end{aligned} \tag{3}$$

Since N represents the sum of the elements in *PC* and in *ADOP*, *(N = PC + ADOP)*, the number of combinations between Potential Customers and Adopters is

$$\begin{aligned} &= \frac{1}{2}\left[(\mathrm{PC}+\mathrm{ADOP})^2 - (\mathrm{PC}+\mathrm{ADOP})\right] \\ &= \frac{1}{2}\left[\mathrm{PC}^2 + 2 \times \mathrm{PC} \times \mathrm{ADOP} + \mathrm{ADOP}^2 - \mathrm{PC} - \mathrm{ADOP}\right] \end{aligned} \tag{4}$$

After regrouping and collecting terms, we can also write

$$= \frac{1}{2}\Big[\underbrace{2 \times \mathrm{PC} \times \mathrm{ADOP}}_{\substack{\text{Communication}\\ \text{between}\\ \text{PC and ADOP}}} + \underbrace{\mathrm{PC}^2 - \mathrm{PC}}_{\substack{\text{Communication}\\ \text{within PC}}} + \underbrace{\mathrm{ADOP}^2 - \mathrm{ADOP}}_{\substack{\text{Communication}\\ \text{within ADOP}}}\Big]$$

During group internal communications, both in *PC* and *ADOP*, no incentive to purchase the new product is generated; for the buying decisions of the imitators these communications are neglected, and the process is reduced to the information exchange between Potential Customers and Adopters:

$$D_{IMIT}(t) = q \times PC(t) \times ADOP(t) \tag{5}$$

The coefficient of imitation q defines the conditional probability, that the possible contacts between elements in *PC* and *ADOP* have been established, relevant information has been exchanged and this actually leads to the decision to purchase the new product.

The sum of innovators and imitators in each period establishes the basic equation for the growth and diffusion of a new product and comprises – as a general form – different models of the product life cycle.

$$D(t) = D_{INNO}(t) + D_{IMIT}(t)$$
$$= p \times PC(t) + q \times PC(t) \times ADOP(t) \quad (6)$$

A third class of customers besides innovators and imitators is added: repeat buyers. This category of replacement purchasing reenters the market after their product's life time has passed, and considers a second purchase.

The three flows of buyers together with their associated state variables of Potential Customers and Adopters constitute the core model of innovation diffusion. It is largely composed of generic modules, whose isolated dynamics are well investigated from related studies, e. g. in connection with the spread of epidemics. Without interfaces to other sectors, this kernel generates the typical logistic pattern over time.

A central tenet for innovation management is the control of average unit cost, this is represented in the lower part of Figure 2. The model generates a dynamic cost function from two variables, defining long and short term behavior. The long range standard cost per unit are derived from an experience curve, the actual cost for each period are calculated from the respective standard value modified for production volume variances.

The experience curve assumes a direct relation between cumulated production $X(t)$ (which incorporates a firm's experience) and average standard cost per unit $c^S(t)$, adjusted for inflation; c^S defines standard unit cost at the planned level of production. Every doubling of $X(t)$ is associated with a cost reduction in real terms by a constant percentage:

$$c^S(t) = c_n \, [X(t)/n]^{-\delta} \quad (7)$$

where c_n stands for the cost of unit n $(n \subseteq X)$ and δ represents a constant which depends on the experience rate. For many businesses experience rates of 15 % to 20 % have been observed and ample empirical evidence for this relationship is available.

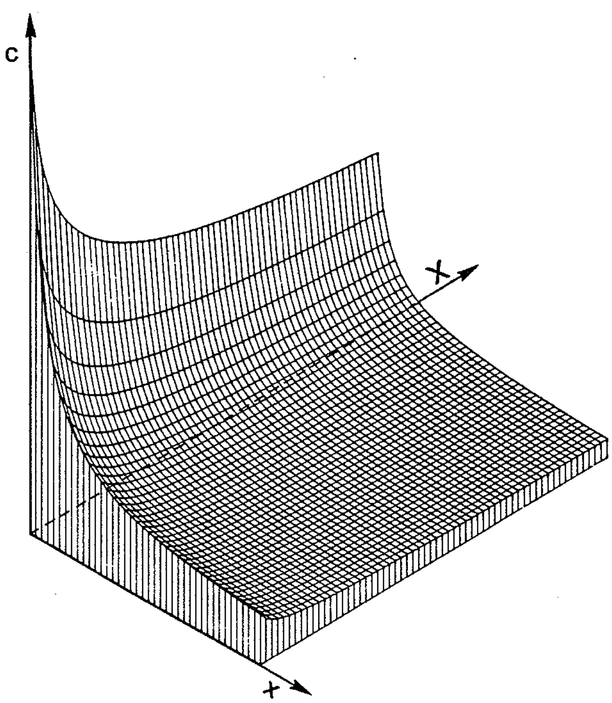

Fig. 3. Graph of the dynamic cost function

The dynamic cost function generated in the model determines actual unit cost in each period

$$c(t) = \phi[X(t), x(t)] \quad (8)$$

on the basis of gained experience $X(t)$ which gives the standard unit cost and the variance resulting from the level of capacity utilization achieved with the output volume $x(t)$ (Figure 3).

To be used as a strategy support tool, relevant managerial variables have to be included. The core model is expanded through sectors defining (i) market development and technological substitution, (ii) product pricing and its impact on operating results, (iii) capital investment and the resulting cost structure, and (iv) production volume and quality control.

Figure 4 shows the run of a model version including market development and substitution. It assumes an initial value of potential customers as the product is launched into the market; additional customers can be gained from an untapped market as diffusion and thereby product awareness proceeds. At t = 15 a new firm or even a completely new industry enters the market, its competing and more attractive product offers a higher level of technical sophistication. A substitution cycle is initiated. Demand declines because (i) the level of potential customers decreases as the number of adopters grows while the untapped market becomes depleted, and (ii) more and more buyers shift towards the substituting technology.

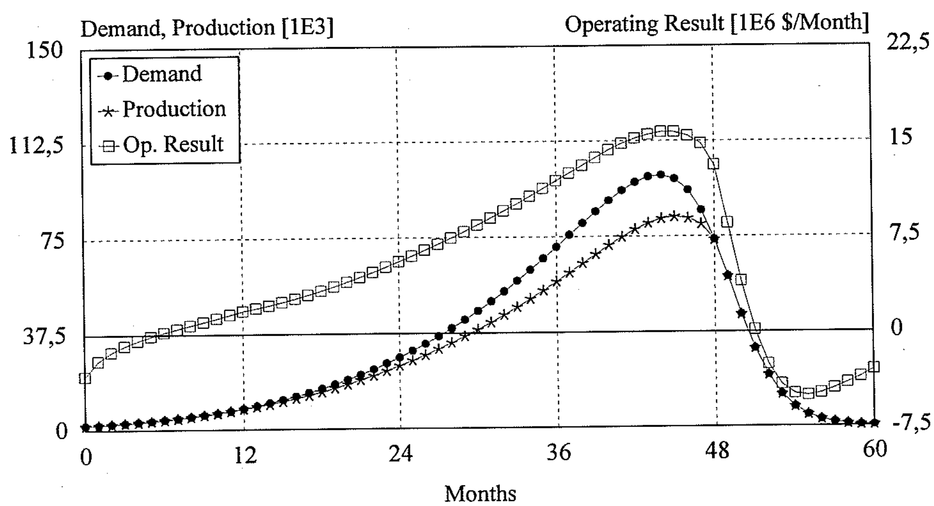

Fig. 4. Reference mode of the innovation diffusion model

The behavior generated in the run of Figure 4 will serve as reference mode for the further analysis. The left scale shows the values for demand and production in thousand units, the right scale defines the operating result in million dollars. The behavior modes of production, demand and operating results duplicate the usual characteristics of a product life cycle. In the early periods, the curves indicate a large number of potential customers being attracted by the innovation. Increased product awareness leads to accelerating demand, even drawing additional customers from the untapped market. In later periods, market volume decreases as the stock of customers becomes depleted and potential buyers shift towards the substituting technology with its superior attributes.

The core model and its extensions form the base of a Strategy Support System. It analyzes the processes of innovation diffusion from the perspective of corporate management. It serves as a simulator to investigate how strategies can foster or hinder market diffusion and profit performance. With such an objective the problems of model quantification and validation in the absence of sufficiently corroborated information are evident. Management, however, has to decide about the timing and the strategy of innovations – even if there are no „hard" data available. Whether this is done on the basis of intuition and mental models or whether formal, computerized support tools are used is only an instrumental question. Computer modeling alleviates communication, enforces precision, and makes at least some of the implicit assumptions explicit; it encourages discussions and builds consensus towards improved decision making.

An Application to Pricing Strategies

Pricing new products is an essential but largely unresolved problem of innovation management. Peculiar difficulties result from the dynamics in demand interrelations, cost development, and the risk of early substitution through more advanced products. In spite of this complex framework for decision making, the development of formal simulation models is considered to be generally inferior to analytical approaches (Friedman 1984). Attempts to derive and to actually apply optimal pricing policies, however, are faced with difficulties, both mathematical and practical. Their results (Jeuland and Dolan 1982) indicate factors to be considered, but the proposed pricing rules appear by far too complicated to support actual pricing decisions.

In the innovation diffusion model four price setting mechanisms are included for direct investigation.

1. Myopic profit maximization with the assumption that there is perfect information on the current state of cost and demand. The optimal price p^{opt} is derived from elasticity of demand $\varepsilon(t)$ and per unit standard cost $c^s(t)$ (the use of standard cost avoids the distorting impact of short term capacity utilization):

$$p^{opt}(t) = c^s(t) \times \frac{\varepsilon(t)}{\varepsilon(t)-1} \tag{9}$$

2. Skimming price strategy serving first customers with high reservation prices and subsequent price reductions (Clarke and Dolan 1984). The model applies a simple decision rule modifying $p^{opt}(t)$ through an exponential function with time constant T:

$$p^{skim}(t) = p^{opt}(t) \times (1 + a \times e^{-t/T}) \tag{10}$$

3. Full cost coverage plus a profit margin π to achieve positive results even during the early stages of the life cycle:

$$p^{fcc}(t) = c^s(t) \times \pi \tag{11}$$

4. Penetration pricing aims at rapidly reaching high production volumes to benefit from the experience curve and to increase the number of adopters. It sets prices according to:

$$p^{pen}(t) = c^s(t) \times \pi \times (1 - a \times e^{-t/T}) \tag{12}$$

To evaluate these policies, the firm's operating result is used as the measure of performance. For all four pricing strategies, Figure 5 compares the simulated market responses. The lower set of curves presents the firm's operating result per period, the upper range of the figure gives the corresponding synopsis for the cumulated and discounted performance.

The figure indicates that in a dynamic environment the classical pricing rule for profit optimization leads to results which - surprisingly - are superior to both full cost pricing and the skimming strategy. The appropriate strategy, however, is the rapid penetration of the market by setting relatively low prices, especially in the early stages of the life cycle. The combined price and diffusion effect stimulates demand, and reduces the risk of loosing potential customers to upcoming substitution products.

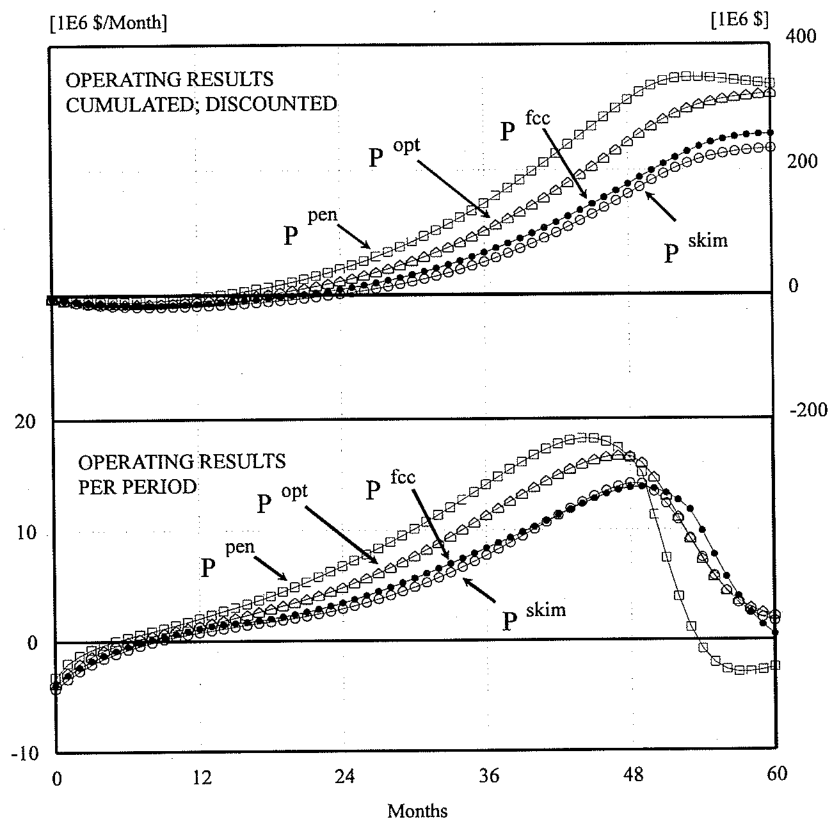

Fig. 5. Synopsis of operating results for different pricing strategies

Towards the end of the simulation run, sales decline so rapidly that production capacity cannot be adjusted in time. The fact, that during the last stage of the cycle fix cost per unit exceeds the contribution margin generated by the achievable prices and hence operating results per period turn negative, may suggest a more cautious investment strategy. Less capital build-up prior to the peak in demand implies less fixed cost and – intuitively – seems to offer the opportunity for a more flexible reaction to the declining market development.

The model is a modularly composed representation of the product life cycle dynamics. It offers the flexibility to be adopted to different innovation types. It allows the analysis of alternative marketing policies for new products. The proposed price strategies serve as examples to demonstrate the model's viability. A strategy of rapid market penetration is suggested to be most promising in a dynamic demand situation where prices influence market growth, where substitution can occur, and where delivery delays eventually accelerate the decision of potential buyers to turn to other products.

Extensions of the model are necessary. They must include direct competition between suppliers of the same or similar products, allow the consideration of different levels of product quality, and the impact of advertising on market behavior. Linked to a data base with market information and controlled by a dialogue system, a collection of such models provides effective decision support for innovation management.

Evaluation of Resource Allocation Policies

To analyze the impact of intra-firm factors, especially with respect to production capacity, the general model was extended. Investment in production facilities - both capital and labor - is based on a comparison between projected demand and available production capacity, both measured in units per period. Since the model is not designed to predict the market success of an innovation per se, but rather to study and comprehend the effects of management strategies on innovation performance, projected demand and actual demand behave rather similar.

Besides demand projection, the firm's willingness to accept risk is explicitly considered in the investment decision. A cautious attitude towards market risks and opportunities will reduce, a more offensive or aggressive behavior will increase the indicated change in capital investment. There will be no financial limitations for the desired investment level, assuming that the requested amount of capital can be made available.

Production Capacity Decision and Order Backlog

Total investment serves two purposes. It provides the capacities required either for actual production purposes or for quality control. Investment comprises all factors (capital goods and human resources) needed in their respective proportions according to an (implicitly assumed) production function.

At the investment stage, no distinction is made between different types of equipment to be procured or personnel to be hired. Both can either be employed for manufacturing new products or for assuring the desired quality level of the process. Even after people have been hired or a specific piece of machinery has been acquired, a reallocation between production purposes and quality control is still possible. Such a shift, however, requires an explicit reallocation decision and must allow a certain adjustment time to take place. In the economic theory of technical change, this situation is analogous to the case of „putty-putty" factors of production (Phelps 1963).

Resource reallocation between both ways of capital usage is monitored by a decision rule based on the firm's readiness for delivery – a relationship between incoming orders and the actual level of production to meet this demand. In a market with short life cycles and the constant threat of substitution through upcoming new, more sophisticated and more competitive products, delivery delays can cause a permanent loss of demand. A strategy to provide the capacities for immediate delivery – even at the cost of less careful quality control – is an effort worth to be considered.

The extent to which a firm's policies of quality management determine the market performance of its innovation, and how they should be planned and controlled is analyzed and evaluated on the basis of the assumption that the price effect upon demand is kept constant for all the simulation runs presented here. Prices are set according to the penetration policy described above.

The decline in potential customers towards the end of the simulation has lead to a sharp reduction in the production rate. A more defensive investment policy, however, would worsen in fact the situation significantly and lead to less production and less sales over the whole period under investigation. It would reduce the achieved operating results substantially. From the early stages of market introduction, unfilled orders hamper the successful launch and the profitable performance of the innovation. Backlog in unfilled orders disturbs the market, amplifies the upcoming trend towards the substituting technology and causes an accelerated loss of potential customers (Milling 1987).

In the opposite, an aggressive policy yields better results. It provides the capacity for a higher rate of production when demand gains momentum. This is achieved at the cost of temporary idle capacity, but the gained benefits exceed by far the negative impact on financial performance. Production volume keeps in close contact with accelerating demand and lets sales and thereby operating results prosper.

Quality Assurance – Reserve Capacity or Competitive Advantage?

A constant fraction of capital investment – for example 10% – is diverted for quality control. This is the means to insure the desired quality level. Equipment for manufacturing and production control purposes is similar, labor has to have equivalent qualifications, they share the same work floor etc. If quality control resources were partly and temporarily reallocated and used to increase output instead of checking standards and tolerances, a significantly higher production volume could be achieved. With this policy, total fixed cost would remain unchanged and consequently operating results would improve.

In addition to an investment strategy, a modified resource allocation procedure is was implemented. It channels capacity between tasks devoted either to production or to quality assurance. If manufacturing capacity does not suffice to meet total demand, the standard emphasis on quality assurance is temporarily reduced to allow a higher rate of production.

Similar to the case of reduced capital investment, the actually obtained results differ from the expected behavior. The discrepancy between demand and production remains indeed negligible, but instead of gaining higher sales and achieving an improved operating performance, the actual outcome is poor. As the customers' level of perceived quality decreases, production and operating result stagnate; they remain in total far behind the values of other courses of action. The otherwise gradual transition of potential demand to the upcoming later technology turns into a rapid and steep decline of market volume.

Quality proves to be a prime competitive factor during all phases of innovation diffusion. In the early stages, it influences market growth and penetration, in the later stages it exhibits an important impact on the rate of imitation and the speed of substitution. Short term advantages resulting from the negligence of quality, e. g. the gain of additional production capacity and reduced cost, turn into severe damages. In a medium and long range perspective, they cause detrimental effects on all relevant variables.

This result from model analysis corresponds fully with empirical observations on the role of product quality and its influence on purchasing decisions. As an immediate consequence it suggests a strategy of emphasized – not reduced – quality control. If manufacturing cannot keep up with demand or incoming orders, improved – not poorer – product quality seems to be appropriate.

High quality standards show a strong influence on buying behavior, they might be used to balance the negative effects of order backlogs and delivery delays. When production volume lags orders booked, customers might be willing to accept waiting for delivery if quality is supreme.

The behavior modes in Figure 6, where the scale for production and demand has been changed to an upper value of 200,000 units and a quality index is plotted as an additional variable with an initial value defined to be 100%, support these hypotheses. Operating results approximately double, compared to the preceding run. With the high production volume, nearly all market potential is exhausted, leaving relatively few customers for the new technology. The reputation of the product – due to its superior and reliable quality – is strong enough to compensate the negative effects of transient difficulties with growing delivery delays.

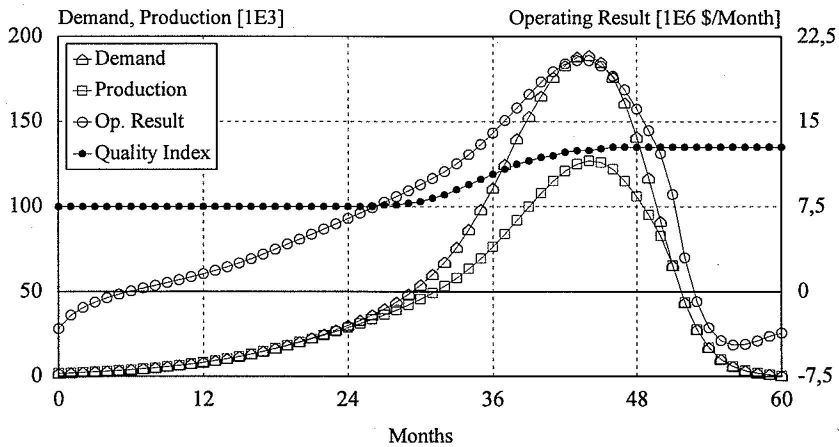

Fig. 6. Emphasized quality in all innovation stages

Especially during the last third of the life cycle, quality becomes the crucial factor. It does not extend the overall economic life time of the innovation significantly beyond the otherwise experienced values. But it causes demand and production to peak at much higher levels and to descend less rapidly. This leaves time to adjust to the change in the rate of production. The profit situation is favorably influenced.

A comparison of total results, i. e. cumulated and discounted operating results over the whole product cycle, indicates that the strategy of offensive capital investment combined with high level quality assurance leads to the best results. With this policy, at the end of the simulation period the firm is financially approximately 30% better off than in the base run's reference mode (Figure 4).

This statement holds true only if the innovation is indeed accepted by the market. An unsuccessful product would leave the firm with ample excess capacity. It would substantially hurt its profit performance. However, if the product fails, the differences in the achieved operating results between the defensive and the offensive production strategy are only marginal. For all strategies analyzed here, innovative firms bear similar risks, but only with sufficient production capacity and tight quality control they can profit from the opportunities.

The willingness to accept risk is a crucial prerequisite for the innovation business. Attempts to reduce or even to evade these hazards lead to poor results. If firms compete in such an environment and launch innovative products, they have to provide the necessary production capacities to assure smooth delivery; temporary excess capacity hurts the financial performance less than longer delivery delays. In all phases of the life cycle, particularly during market maturity and decline, quality is a prime factor of competition. Neglected quality generates – if at all – only short term advantages. The long range negative consequences exceed them by far. The model emphasizes that role of intra-firm factors. Production strategies play a key role in the strive for gaining a competitive advantage.

Investigating the Timing of Innovations

In a dynamic environment with high expenditures for R&D and manufacturing equipment, short product life cycles and a dramatic decay in prices immediately after market introduction time to market and time to volume are essential for innovation management; they are strategic variables in the strive for competitive advantage (Bower and Thomas 1988). A McKinsey study revealed that a six months delay in starting manufacturing a new product can reduce overall earnings up to

33% (Dumaine 1989). Substantial overruns in the production cost or the R&D budget have far less impact. Similar results are reported from other sources and are confirmed by own analyses.

Frequently only the market stage, during which the product is sold, is associated with the notion of an innovation. However, before the availability of a marketable product the costly, lengthy and risky period of research and development has to be passed successfully. While the market cycle tends to become shorter and to reduce the time for the corporations to earn their money, the research and development phase requires increasingly more time, personnel and financial resources. These diverging trends make it difficult to achieve a satisfactory profit performance. A comprehensive investigation into innovation dynamics must cover both, the development and the market cycle.

The integrated model consists of two modules (Figure 7). They are linked through flows of information to monitor the resource allocation, the intensity of the R&D-processes, the required minimum quality level before a new product is considered ready for market introduction, etc.

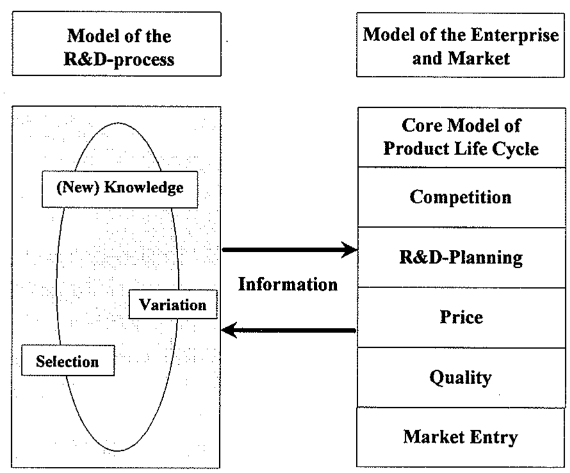

Fig. 7. Components of the Integrated Innovation Model

The R&D-module deals largely with intangible processes. Many attempts were made to define a production function for research and development, using as input the allocated resources like budget, number of people assigned to the task, equipment available, etc. In general, these attempts were not successful in describing how the various factors operate together to achieve the desired results. In this model a different approach is used. An analogy to biological evolution theory defines how new concepts develop by the variation and mutation of existing and known solutions. The respective results are evaluated on the basis of viability. If they seem to be superior to previous combinations, they are selected for further development, i.e. as the basis for future evolution. Otherwise they are discarded. This evolution module is a C-written algorithm that is linked to and interacts with the production and market part of the model.

When the evolution algorithm is run as a stand-alone module – without interference from the production and market part of the integrated model – it generates the chain of subsequent products at an increasing level of technological sophistication. In the long run, it creates the S-shaped curve enveloping the technological development of individual innovations.

The model is a conglomerate of information and data from several sources. It draws on the concepts of innovation diffusion as they are widely accepted in the scientific literature; it uses statistically corroborated data whenever they are available. Yet a large part of the information comes from less rigorous sources; it results from presentations and discussions with managers where the model had to pass kind of a Turing-test (Turing 1950): The structure of the model was critically analyzed by experts in the field. It was speculated about possible reactions to managerial actions. Results were compared and evaluated against the respective experience. Finally the model's actual behavior modes were considered to be meaningful representations of real world responses. Despite these endeavors, the claim for model validity – especially of its development module – remains modest.

Figure 8 shows a simulation run of the model with both modules coupled. It is assumed that at the time the innovation is launched, three competitors are in the market. The firm under investigation and its main competitor hold initially the same market share, and in this base run they offer identical products and follow the same strategies. They thus allocate both the same resources for R&D, they choose the same timing for bringing new technologies to the market, they offer the same quality, etc. Consequently the life cycles for both firms virtually overlap.

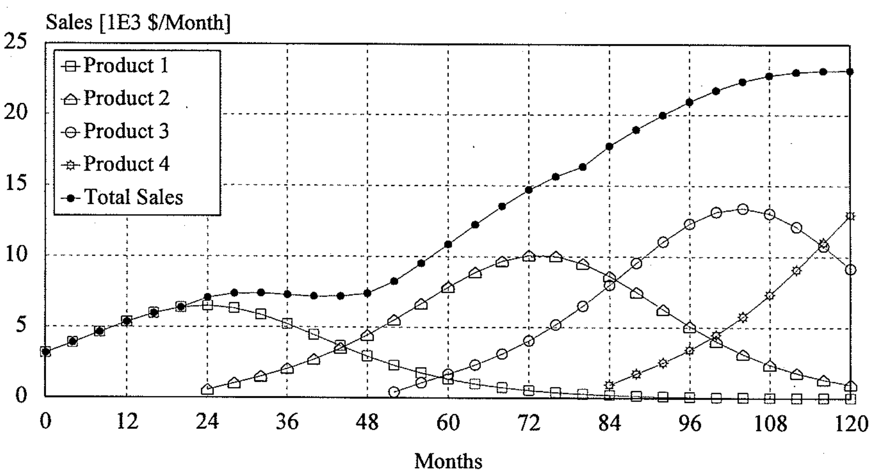

Fig. 8. Base mode of the Integrated Innovation Model

The curves emphasize the importance to provide a steady flow of new and improved products. Without such a replacement of older technologies, sales and profits will soon start to deteriorate. Firms cannot successfully rely on one single innovation, they must be based on a corporate philosophy, which understands innovation as a permanent task. However, entering the market with an innovation too early, increases the risk to fail. Potential customers might still be unprepared for the new technology; quality might not yet be fully mastered; shipping delays might occur because of disturbances during the start of production, etc. On the other hand the early launch of an innovation offers attractive opportunities. Decisive competitive advantages might be achieved and sustained. A dominant market share is difficult to attack from competitors following a me-too strategy.

Implications for Corporate Planning and Management Education

The model presented here is designed in a modular fashion, and offers the flexibility to be adopted to different types of innovations. It provides – even for situations that exceed the capabilities of analytical methods – the possibility to study different courses of actions in the setting of a management laboratory. In the real world, already a very few variables suffice for a complete misperception of a decision situation (Sterman 1989). Strategy Support Systems combine human creativity and judgment with the capabilities and the power of high speed computing.

The concept of decision support is linked to notions like learning, interaction and evolution. It emphasizes the process of learning in developing a strategy rather than the final result; the interactions with different facets of a problem lead to a better understanding than the application of prefabricated procedures; problem solving should be the result of an evolutionary process not an automated choice (Checkland 1985). The capability of the firm to adapt and to learn faster than its competitors might be the only defensible competitive advantage it has in the long run (de Geus 1988).

The ultimate purpose of effective planning in complex systems is not to produce plans but to change the mental models of the decision makers. Strategy support systems function as catalysts. They help to clarify complex internal images and to analyze them. They demonstrate how action and reaction, stimulus and response, or cause and effect fall apart. The knowledge and the technical requirements for the development and application of such kind of decision support are available; their applications make individual decision processes become more transparent and to converge. Adequately used, strategy support systems provide a better understanding of the problem under investigation, they allow a faster reaction to market developments and the achievement of decisive competitive advantages.

Gaming in Management Education

Management games of the type discussed here have the objective to utilize the potential of Strategy Support Systems for individual and organizational teaching and training. Through the artificial reality of applied causal models, a thorough learning process can be initiated. The expected benefits of such an endeavor justify the substantial efforts required. The interactions with computer simulation models allow insights into the behavior of systems. The gaming approach to management education and training combines the abstract investigations of theoretical science and the practical research of laboratory experiments. It constitutes a third pillar for progress toward more rational decision making. Through the process of iterative cycles of "playing", the intrinsic properties of the problem will be better understood. An *a priori* experience for the actual course of actions will be gained in the virtual reality of the game (Milling 1990).

To meet these ambitious objectives, a management gaming simulator for innovation management should (i) improve decision making, (ii) teach Systems Thinking, and (iii) encourage Cooperative Learning. Decision making under time pressure is a daily managerial routine. Due to the real life consequences of the actions taken, usually no rehearsal of this process is feasible. In spite of the vital importance of their policy choices, management and especially senior management acts always "on line". On the job training, learning by doing or by trial and error are hardly possible. Available and proven techniques from information gathering to decision assessment and evaluation can only seldom be acquired and tested without immediate and very real repercussions. Here, management gaming provides a very useful setting, especially for group decision making (Scheper 1991). All actions taken occur in the virtual reality of a computer model only. Trainee activities, like the mentioned on the job training, etc., highlight the potential benefits of the approach.

A simulation model for generating data for a management game must comprise a realistic structure and stable policy rules. The players should be able to use their professional knowledge and their business experience, and thus, the model should be „tolerant" enough to accept a broad spectrum of input values without generating unrealistic modes of behavior. There are, however, limits for the quantity of information the players can handle. They should be able to understand the sometimes complex relationships between the decisions and the reaction of the model.

A Microworld for Innovation Management

The basic modules of the Innovation Management Simulator represent several structural identical industrial corporations, competing for the same group of potential customers. Four groups of players emulate the boards of directors of virtual enterprises, that compete with each other (Figure 9). At the beginning of the game, all corporations have a product with the same level of technological sophistication and with the same market share. In the course of time, the firms can develop new generations of products which compete with the different technological generations in their own Portfolio and those of other firms. R&D resource allocation and the timing of market introduction, investment and production planning, cost management and pricing policies, product quality and delivery delays are key control variables in these processes.

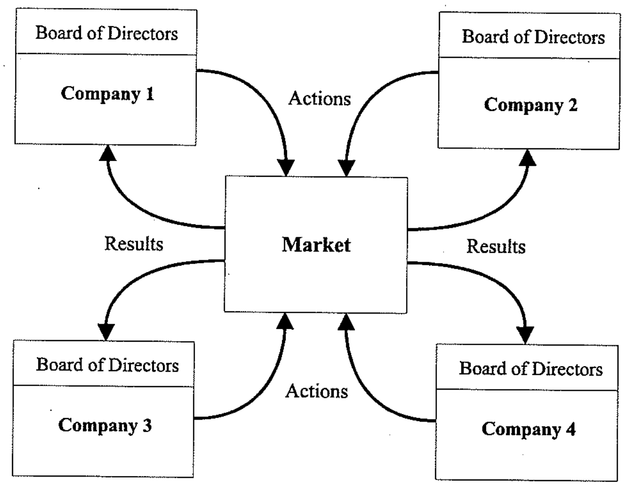

Fig. 9. Modules of the Innovation Management Simulator

During the game, each group of players is confronted with interrelated decision making requirements, and it is difficult to understand how they interact and how the whole system will react. To improve the performance, the group must identify and collect relevant information. The team members must derive alternative courses of action and evaluate their expected consequences. A feeling for complex system behavior should be gained (Vennix 1990).

Successful corporate management requires specialization, the separation of tasks, which finally lead to "Taylorism", and the delegation of decision making. But the same developments bear the risk of failure through uncoordinated activities; management becomes futile without coherent and unambiguous action. Especially in the dynamic environment of innovation management this (potential) gap between isolated operations and coherent strategy has to be closed. Team or Cooperative Learning is necessary to define and to achieve the overall corporate objective (Senge 1990; Argyris 1990). Management games work as catalysts in such a process of group decision making. They counteract narrow specialization, lead to improved communication between different corporate functions, and encourage the identification and the pursuit of shared values and overall objectives.

In many business games the students play against an imaginary competitor represented through the computer. In such an environment players might blame the failure of a strategy to the supposedly unrealistic representation of the real world situation through the game. Players discuss the shortcomings of the computer model instead of analyzing the real problem. The Innovation Management Simulator presented here uses the computer only to clear the market, to calculate costs, profits or the results of R&D efforts. Unexpected behavior is not caused by an inadequate model. Players realize the causes in their own decision or those of the competitors. The players recognize the usefulness of different management tools and heuristics – like the experience curve or the product life cycle. They experience the difficulties to succeed in a complex and dynamic environment with decision which rely solely or mainly on intuition.

Even though management games reduce the real world complexity and make concessions to reality, strategic and systems thinking can be learned effectively. It is important, however, to reduce the video game syndrome and to avoid the impression that it is played against a computer. Only if the players accept that their own strategies cause the behavior of the microworld, they will learn for future real world actions.

Experiences with management games shows them as powerful tools to support business education. They also provide excellent opportunities to improve group decision making and to practice the performance in a dynamic environment without the fear of irreversible actions. They indicate, that reading the relevant literature, participating in class room discussions and attending lectures are important for learning the basics; they can effectively be supported by management games.

References

Argyris, C. 1990. *Overcoming Organizational Defenses. Facilitating Organizational Learning..* Boston: Allyn and Bacon.

Bailey, N. T. J. 1957. *The Mathematical Theory of Epidemics*. London.

Bass, F. M. 1980. The Relationship between Diffusion Rates, Experience Curves, and Demand Elasticities for Consumer Durable Technological Innovations. *Journal of Business*. 53:S50-S67.

Bass, F. M. 1969. A New Product Growth Model for Consumer Durables. *Management Science*. 15:215-227.

Bower, J. L. and T. M. Hout. 1988. Fast-Cycle Capability for Competitive Power. *Harvard Business Review*. 66(6): 110-118.

Checkland, P. 1985. From Optimization to Learning: A Development of Systems Thinking for the 1990s. *Journal of the Operational Research Society*. 36: 757-767:

Clarke, D. G., and R. J. Dolan. 1984. A Simulation Analysis of Alternative Pricing Strategies for Dynamic Environments. *Journal of Business*. 57:S179-S200.

Dumaine, B. 1989. How Managers can Succeed Through Speed. *Fortune*, No. 4, February 13: 30-35.

Forrester, J. W. 1961. *Industrial Dynamics*. Cambridge, MA: M.I.T. Press.

Friedman, J. W. 1984. Comments on 'Simulation Analysis of Alternative Pricing Strategies for Dynamic Environments'. *Journal of Business*. 57:S201-S204.

Georgescu-Roegen, N. 1971. *The Entropy Law and the Economic Process*. Cambridge, MA: Harvard University Press.

de Geus, A. P. 1988. Planning as Learning. *Harvard Business Review*. 66(2): 70-74.

Jeuland, A. P., and R. J. Dolan. 1982. An Aspect of New Product Planning: Dynamic Pricing. ed. A. A. Zoltners. *TIMS Studies in the Management Sciences*. 18: 1-21.

Linstone, H. A., and D. Sahal, eds. 1976. *Technological Substitution. Forecasting Techniques and Applications*. New York, NY: Elsevier.

Mahajan, V., and E. Muller. 1979. Innovation Diffusion and New Product Growth Models in Marketing. *Journal of Marketing*. 43:55-68.

Milling, P. M. The Impact of Pricing Strategies on Innovation Diffusion and R&D Performance (with Frank H. Maier). *System Dynamics: An International Journal of Policy Modeling*. (in press)

Milling, P. M. 1994. Management Games for Group Decision Making in a Dynamic Environment (with F. Lehmann). *System Dynamics: Exploring the Boundaries*. ed. E. F. Wolstenholme. Sterling (Scotland). pp. 83 – 92.

Milling, P. M. 1991a. Quality Management in a Dynamic Environment. *The Cybernetics of Complex Systems – Self-organization, Evolution, and Social Change*. ed. F. Geyer. Salinas, CA: InterSystems Publications. pp. 125 – 136.

Milling, P. M. 1991b. An Integrative View of R&D and Innovation Processes. *Modelling and Simulation 1991*. ed. E. Mosekilde. San Diego, CA. pp. 509 — 514.

Milling, P. M. 1990. The Design of Strategy Support Systems. *Advances in Support Systems Research*. ed. G. E. Lasker and R. R. Hough, Windsor: I.I.A.S. pp. 227 – 231.

Milling, P. M. 1987. Manufacturing's Role in Innovation Diffusion and Technological Innovation. *Proceedings of the 1987 International Conference of the System Dynamics Society.* Shanghai. pp. 372-382.

Milling, P. M. 1986a. Diffusionstheorie und Innovationsmanagement. *Innovations- und Technologiemanagement*. ed. E.K.O. Zahn. Berlin: Duncker & Humblot. pp. 49 – 70.

Milling, P. M. 1986b. Decision Support for Marketing New Products. ed. J. Aracil, J. A. D. Machuca and M. Karsky: *System Dynamics: On the Move.* Seville. pp. 787 – 793.

Morecroft, J. D. W. 1984. Strategy Support Models. *Strategic Management Journal*. 5:215 -229.

Norton, J. A., and F. M. Bass. 1987. A Diffusion Theory Model of Adoption and Substitution for Successive Generations of High-Technology Products. *Management Science*. 33:1069 – 1086.

Pearl, R. 1924. *Studies in Human Biology*. Baltimore.

Phelps, E. S. 1963. Substitution, Fixed Proportions, Growth and Distribution. *International Economic Review.* 4: 265 – 288.

Rogers, E. M. 1983. *Diffusion of Innovation.* 3rd. ed., New York, NY: The Free Press.

Scheper, W. J. 1991. *Group Decision Support Systems. An Inquiry into Theoretical and Philosophical Issues*. Diss. University of Brabant, Tilburg.

Senge, P. M. 1990. *The Fifth Discipline: The Art and Practice of the Learning Organization.* New York: Doubleday.

Sterman, J. D. 1989. Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Environment. *Management Science.* 35: 321-339.

Turing, A. L. 1950. Computing Machinery and Intelligence. *MIND.* 59: 433-460.

Vennix, J. A. C. 1990. *Mental Models and Computer Models. Design and Evaluation of a Computer-Based Learning Environment for Policy-Making*. Diss. University of Nijmegen.