TIME - A KEY FACTOR IN CORPORATE STRATEGY

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ABSTRACT

Empirical analyses indicate that the firm which is the first in bringing new products to the market has a major competitive advantage. The development time for sophisticated and high quality products is shortening. The time span of the market cycle is decreasing, and for high technology firms, even rather short delays can cause a deep cut in the overall profit performance. In the "Factory of the Future" the capability for immediate and reliable delivery of custom designed products is a crucial aspect.

Speed is becoming a decisive factor for corporate management. In Management Science, however, this development is not yet taken into account adequately. Different stages of the same process are still analyzed separately. Models of research and development e. g., do not investigate how delays influence the market performance of the eventually achieved product. Studies of innovation diffusion focus solely on the market cycle, thereby neglecting the lengthy and costly R&D processes. With such a limited perspective, those models must fail to support effectively decision making in a dynamic high technology environment.

The paper discusses System Dynamics' role in such a setting. It presents a model for innovation management which integrates the stages of R&D with the production and marketing cycle. It is designed as a microworld for learning about the system and for studying possible ways of influencing its behavior. The model consists of two modules: a C-written algorithm, based on biological evolution theory, maps the firm's research and development processes; the second module is a Dynamo-representation of innovation policies and market dynamics. Both modules are tightly coupled through flows of information. Their interactions allow the testing of corporate strategies for R&D planning and innovation management.

Although still in the development stage, the model provides insights into the timing of decisions. The results from this integrative view underline the importance of speed in the strive for competitive advantage.

THE DYNAMICS OF TECHNICAL CHANGE

In corporate management the product life cycle frequently serves as a powerful heuristic. It is applied to outline the dynamics of market growth and decay. Its logistic curve is used to forecast expected sales. The portfolio approach in strategic planning focuses of the different stages of product maturity to determine the competitive position of a firm.

Most formal models generating the cycle's characteristic sigmoid curve, however, do not reflect properly the factors causing this behavior. They either use specific mathematical functions to produce a predetermined behavior mode or are based upon biological or physical analogies. They fail to take sufficiently into account the economic environment of cost and prices, quality and in-time delivery, etc. Purchasing decisions do not follow the same natural laws as do the spread of a disease, the dissipation of particles or similar processes, which were the original study objects in the natural sciences.

Furthermore, most of these models reflect the diffusion, not the evolution of a phenomenon. They concentrate on - and thereby isolate - the short term dynamics of an innovation.They do not explain the substitution processes between a sequence of products at different levels of sophistication which take place as technology advances. Figure 1 shows this sequence of life cycles for the sales of PC micro processors. It emphasizes the dynamics of change as the transition from one level of technology to the next takes place.

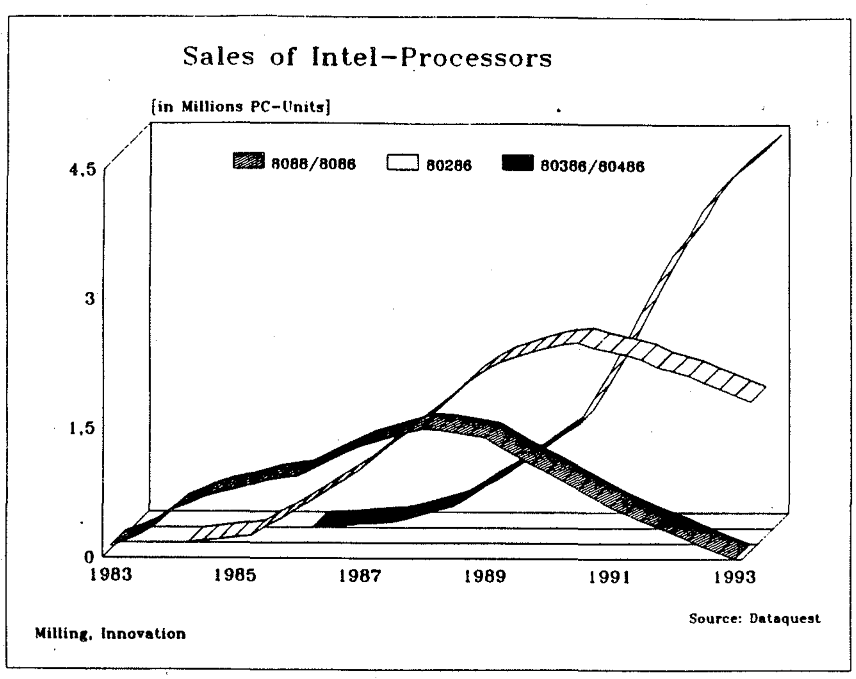

Fig. 1: Transition between Levels of Technology: Sales of Intel Processors in Europe.

Due to the dynamics of innovative products, transition between technologies can occur rapidly, leaving the firm little time to sell the product and to earn its return on investment. While in the above figure, only one corporation controlled and nearly monopolized the market; in the areas of high technology there is frequently fierce competition. The sales and price development of dynamic random access memory chips (DRAMs) in Figure 2 exemplifies such a situation.

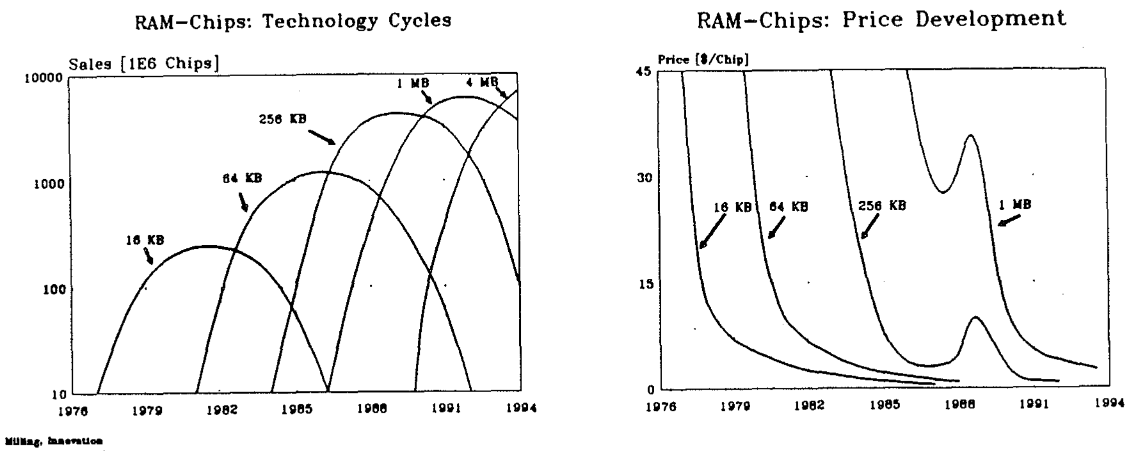

Fig. 2: Sales and Price Development of DRAM Chips.

Each new generation brought along a quadrupling of its storage capacity and a significant increase in production volume. With large scale integration grew the number of production operations, and the development cost increased progressively. In 1985 investment requirements for a state of the art factory were in the range of $ 50 million, four years later they reached $ 250 million. DRAMs are manufactured by more than a dozen companies, and - despite their sophisticated design and delicate production processes - are traded like commodities. Competition leads to a rapid decline in prices immediately after the new technology entered the market. Trailing the leader's race to market by only a short time, makes it very difficult to achieve a sound economic performance.

In general, high expenditures for R&D and manufacturing equipment, short product life cycles and a dramatic decay in prices immediately after market introduction characterize this field - a constellation which is called a *dynamic environment.* Here it is vital for the companies to build up in time the production capacity required; delivery must be fast when demand gains momentum. Only early in the life cycle can high prices be charged; during this stage the firm must earn its compensation for research and development expenditures, the investment in production equipment and facilities, and for the general risk taken.

In a dynamic environment, speed becomes a competitive factor of a strategic dimension. Time to market and time to volume are essential for innovation management. A McKinsey study revealed that a six months delay in starting production of a new product can reduce overall earnings of up to 30 % (Dumaine 1989). Similar results are reported from other sources and are confirmed by own analyses.

Such kind of a problem description might suggest a strategy of high pricing together with an early provision of production capacity. This, however, also implies high fixed cost and little flexibility if demand were overestimated or the market is in its downswing. Furthermore, a policy of skimming prices during the introduction of a new technology might cause slow market penetration; it might impede innovation diffusion and the gain of market share. Without rapidly expanding production volume, only little benefits can be drawn from experience and learning processes. These contradicting aspects emphasize the need for a thorough understanding of the complex decision making parameters and their mutual interactions.

The speed of innovation diffusion and the risks of upcoming substituting products are not solely and not even mainly determined by factors outside the firm. Corporate strategy produces, or at least co-produces innovation dynamics. 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. They are also indicators for successful innovations.

Innovation management requires decisions whose effectiveness are fundamentally important for the competitiveness and the viability of an enterprise. Decision making at this level of complexity cannot be automated, but it is possible to support it by means of formal models and computer based systems. These Strategy Support Systems link cognitive processes to computer routines and gain synergy from this combination (Morecroft 1984). The expected benefits justify the substantial efforts required. Computer simulation allows insights into the behavior of systems. It combines the theory based investigation and the practical research of laboratory experiments and constitutes a third pillar for rational decision making.

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 which 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, can they be meaningful tools to improve managerial decision processes.

Innovation planning and control is seen as a learning process about the system and its environment. 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 iterating processes of model design and model analysis the intrinsic properties of the problem will be better understood (de Geus 1988; Hayes, Wheelwright and Clark 1988; Milling 1989b; Stata 1989).

AN INTEGRATED INNOVATION MODEL

To study the implications of innovation strategies, a general causal simulation model was developed. 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 lies the costly, lengthy and risky period of research and development. While the market cycle tends to become shorter and 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 innovation model consists of two modules: one reflecting the processes of R&D, the other representing the market cycles. Figure 3 shows the structure of the overall model and its components. Both modules 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.

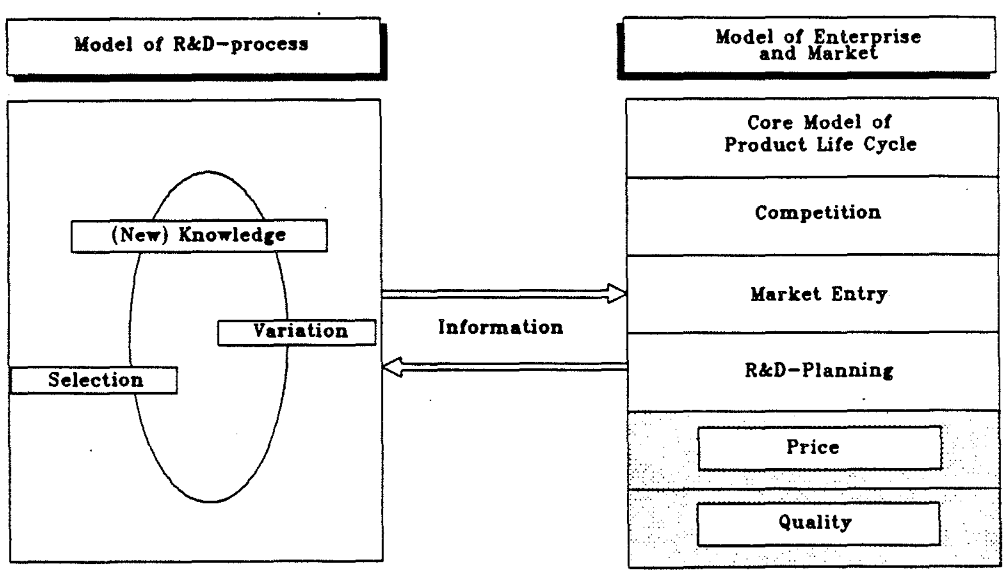

Fig. 3: Coarse Structure of the Integrated Innovation Model.

The module of the research and development phase 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, time and 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 development algorithm is run as a stand-alone module - without interference from the production and marketing 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 the individual innovations .

The production and market structure is based methodologically upon the System Dynamics paradigms, i. e. the feedback perspective of social systems and the use of computer simulation for gaining a better understanding of its properties. Professional DYNAMO plus was used to represent the module, to link it to the evolution algorithm through the External Function facility, to simulate and analyze the total model.

The intrinsic structure of the market penetration processes is derived from the classic epidemics model; the interactions between potential and actual buyers generate the characteristic behavior of a life cycle. This part of the overall model was described in detail elsewhere (Milling 1986). The kernel is extended to include - among others - such aspects as investment in production capacity, quality control, cost performance and pricing strategies[1].

In the core model three categories of customers, their different buying behavior, and the respective shift in dominance between them, are taken into account: innovators, imitators, and - in the later stages - repeat or replacement purchasers. They differ in their reactions with respect to the already achieved market penetration, prices charged, and product quality. This differentiation is frequently found in innovation literature (Bass 1980, 1969; Jeuland and Dolan 1982; Rogers 1983).

The model's investment in production facilities is based on a comparison between projected demand and available production capacity, both measured in units per period. Since primarily, the model is not designed to predict the market success of an innovation but rather to study and comprehend the effects of management strategies on innovation performance, projected demand and actual demand behave rather similar. This alleviates the task of demand forecasting.

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1 All extensions described in the following paragraphs are indeed implemented and were investigated to study particular innovation strategies. The simulation results discussed in the subsequent section of this paper, however, were obtained with not all sectors activated.

Besides required capacity, 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 are no financial limitations for the desired investment level, assuming that the requested amount of capital will be available.

Total investment serves two purposes, it provides the needed capacities for production purposes and those allocated to quality control. Investment comprises all factors (capital goods and human resources) in their required respective proportions according to an (implicitly assumed) production function. At the investment stage, no distinction is made between the two operations; the facilities can either be employed for manufacturing new products or for assuring the desired quality level of the process. Even after personnel has been hired or specific equipment has been acquired, a reallocation between production purposes and quality control is 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, an analogous situation is characterized by "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 a constant threat of substitution through upcoming new 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 - might be an effort worth to be considered. However, as the level of perceived quality decreases, production and operating result will stagnate; they will remain far behind the values of other courses of action. The otherwise gradual transition of potential customers to a later technology becomes very rapid and leads to a steep decline of sales volume.

Quality turns out 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.

High quality does not extend an innovation's economic life time significantly, but it causes demand and production to peak at much higher levels and to descend from there less rapidly. This leaves time to adjust to the change in the rate of production. The profit situation is favorably influenced - an observation that corresponds fully with empirical data on the role of product quality and its influence on purchasing decisions (Milling 1989a, Huibregtsen 1989).

To study the impact of pricing, the model contains an elaborated set of strategies. Although in the short run prices can be set without explicitly striving for full cost coverage, such a policy is not sustainable in the long run; prices must be related to cost. Manufacturing's performance influences cost, prices and demand, which then feeds back to cost. The dynamics of these interdependencies have specific consequences for innovation pricing.

A central tenet for innovation management is the control of average unit cost ,which in turn depends heavily upon the selected pricing strategy. The model derives actual unit cost on the basis of two variables: long term developments on one hand, which are dominated by the impact of learning or experience, and short term capacity usage with its accompanying fix cost influences on the other hand[2]. The long range standard cost per unit are derived on the basis of accumulated production volume. The actual cost for each period are calculated from the respective standard value modified for production volume variances. The dynamic cost function generated in the model determines actual unit cost in each period

$$c(t) = \phi\ [X(t),\ x(t)] \qquad (1)$$

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).

In a dynamic environment where the number of customers is influenced by the level of adopters and where technological substitution can occur very rapidly, it is crucial for the firm to gain a large market share and achieve rapid diffusion of the product. Prices are set according to a policy:

$$p(t) = c^{p}(t)*\pi*(1-a*e^{-t/T}) \qquad (2)$$

where π defines the profit margin on top of long run standard cost. The use of standard cost prevents the otherwise typical effects of full cost pricing. Multiplication with the exponentially decaying factor with time constant T reduces prices in the first months after market introduction, and induces rapid innovation diffusion during introduction. This policy - among others - is discussed in Milling (1988); it has been proven the most effective one in a dynamic environment. A control theoretical analysis of dynamic pricing with similar results but which derives at an optimal solution is provided by Jeuland and Dolan (1982).

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2 The experience impact on cost assumes a direct relation between cumulated production X (which incorporates a firm's experience) and average unit cost c^p, adjusted for inflation; c^p defines standard unit cost at the planned level of production. Every doubling of X is associated with a cost reduction by a constant and predictable percentage:

$$c^{p}(t) = c_{n}\ [\ X(t)\ /\ n]^{-\delta}$$

where c_n stands for the cost of unit n ($n \leq X$) and δ represents a parameter which depends on the experience rate. For many businesses experience rates of 15 % to 25 % have been observed. Empirical evidence for this relationship and a discussion of the implications for corporate strategy are provided in (Henderson 1968).

The core model with its extensions forms the base of a strategic Decision 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 and makes at least some of implicit assumptions explicit; it encourages discussions and builds consensus towards improved decision making.

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.

INVESTIGATING THE TIMING OF INNOVATIONS

The extent to which a firm's policies determine the performance of its innovation, how they should be planned and controlled is analyzed and evaluated on the basis of the following assumptions:

(1) The products under consideration can be thought of as a technologically sophisticated consumer durable likes CD players, video recorders, etc. Competition can and will occur at a micro level between different firms and at a macro level between different states of technology. There will be substitution when an economically more attractive product is available or when a superior technology is introduced at competitive terms into the market.

(2) Production on stock - at least at a level significant for the analysis - is not possible. When incoming orders stay below capacity, the level of output is adjusted accordingly. Over the ten years time horizon of the analysis such an assumption is realistic.

(3) The overall market acceptance of the innovations is assumed. The model serves as a simulator to study how individual strategies can accelerate or hamper market penetration and profit performance. It is not the objective to predict market success or failure of an innovation.

Figure 4 shows a simulation run of the model with both modules coupled. Although the outcome is similar to Figure 1, the underlying scenario is quite different. 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[3].

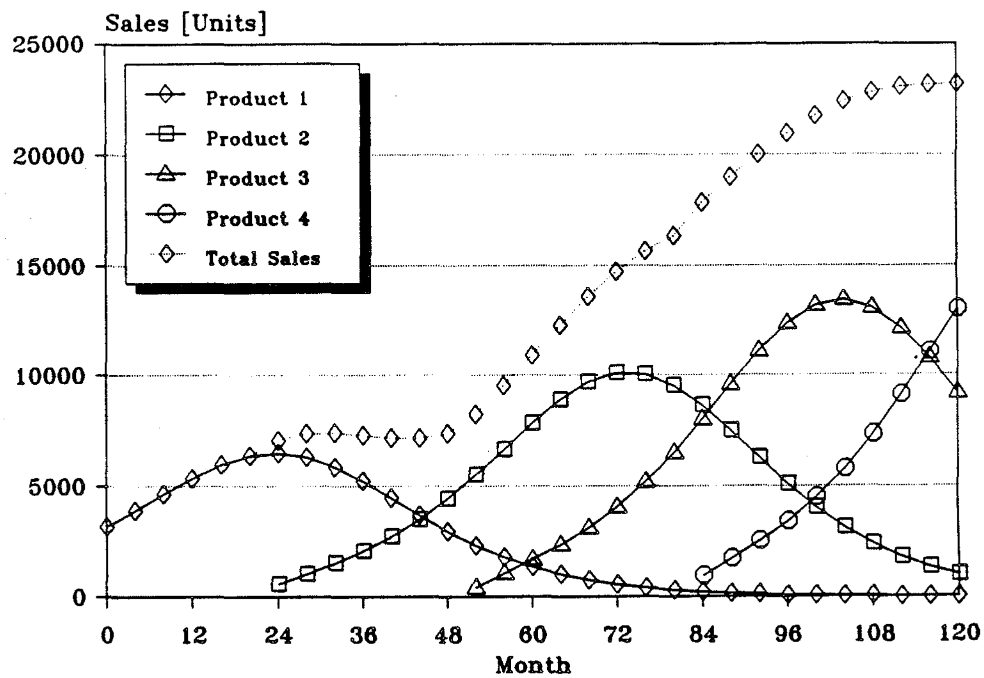

Fig. 4: Base Mode of the Integrated Innovation Model.

The behavior of production or sales volume and the development of operating results duplicate the usual characteristics of a product life cycle. In the early periods, a large number of potential customers is attracted by the innovation. Increased product awareness leads to accelerating demand. In later stages, the remaining market volume is reduced from two sides: the number of potential customers declines and even they start to shift towards the substituting technology with its superior performance and product attributes.

The curves emphasize the importance - for corporations in general and high technology firms in particular - to provide a steady flow of new and improved products. Without

[3] The required computation time to produce this output is rather long. On an IBM PS/2 Mod. 70 386 with 25 MHz it takes approximately 45 minutes for one run. The time depends mainly upon the size of the "Technology Matrix" used in the algorithm and the number of iterations per cycle.

such a replacement of less sophisticated 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.

Entering the market with an innovation too early increases the risk to fail. Potential customers might still be unprepared for the 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.

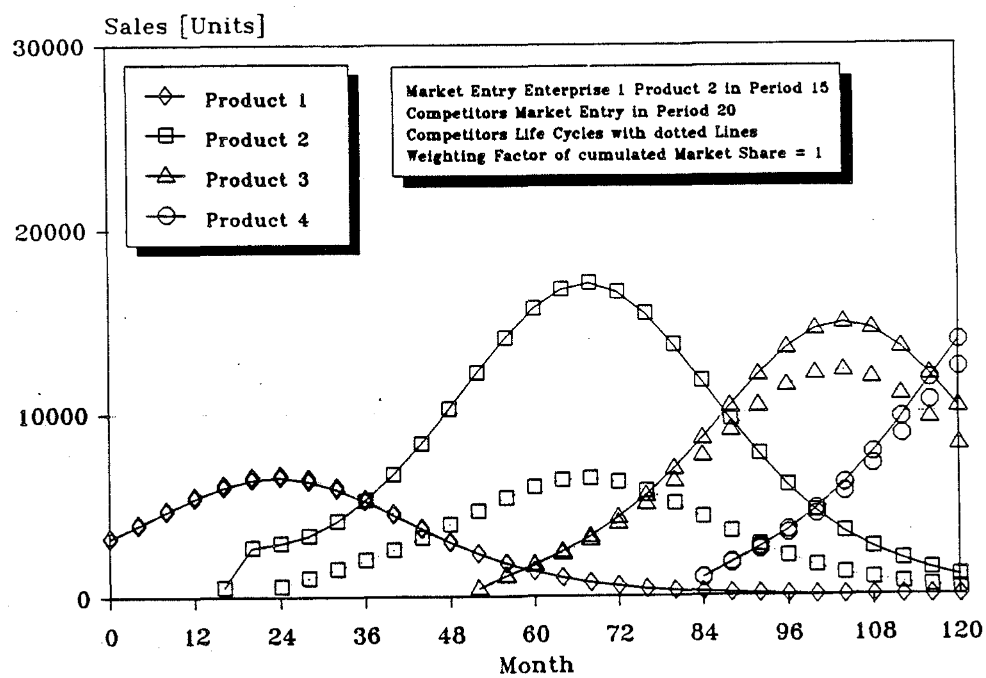

Fig. 5: Earlier Market Entrance of Corporation 1.

In the run it was assumed that all competitors enter the market with their new generation of products exactly at the same points in time. In the following Figure 5 this assumption is waived; Enterprise 1 enters now 5 months earlier, at t=15, while the two competitors make their market appearance at t=20. All other policies and all future entrance dates remain unchanged. Figure 5 shows only the curves for the main competitors. For the first innovation both life cycles overlap; for second product with the higher level of technological sophistication the differences in sales become very substantial.

At its maximum, the delayed product reaches a sales volume which remains approximately at only one third of the value achieved by its faster competitor. It can never recover from its late market entry. And - although the future entry times are the same for all competitors - the firm has acquired superior resources. It can devote more means to developing and marketing later innovations. A sustainable competitive advantage was gained through speed.

IMPLICATIONS FOR CORPORATE PLANNING

The results of the model analysis hold true only if the innovations are indeed accepted by the market. Unsuccessful products would leave the firm with ample excess capacity and hurt its profit performance. The willingness to accept risk is a crucial prerequisite for the high technology business. Attempts to reduce or even to evade these hazards lead to poor results. If firms decide to launch innovative products, they have to provide the necessary production capacities to assure smooth delivery. Time to market and time to volume are strategic variables in the strive for competitive advantage (Bower and Thomas 1988).

The model emphasizes that the market performance of innovations is heavily influenced by intra-firm factors. It is not only price and advertisement that have a profound impact on demand. The life cycle - in its time pattern as well as in its absolute volume - is significantly controlled by the corporation's internal decision making. Management of research and development, production scheduling, shipment logistics etc. influence the performance of technological innovations. Newer developments in production technology and production planning, e. g. concepts like Computer Integrated Manufacturing or the "Factory of the Future", will even accentuate these results.

Well designed computer simulation models allow an effective investigation into such a complex problem situation. They contribute to an improved understanding of the multiple interactions in a dynamic environment. Through computer-based decision support tools, management can improve its perspective and understanding of reality and achieve more effective decision making.

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 the capabilities of 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 facetes 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 defendable competitive advantage it has in the long run (de Geus 1988).

The ultimate purpose of effective planning in complex systems does not lie in producing plans but in changing the the mental models of the decision makers. Decision support systems function as catalysts. They help to clarify complex internal images and to analyze them.The 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 is available; their application make individual decision processes to 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.

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