Integration of Knowledge-based Systems and System Dynamics Models for Decision Support in Innovation Management

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Abstract

Traditional models of innovation diffusion ignore the complexity and dynamics underlying the process of diffusion. Usually these models consider only a single management decision variable, e.g., price or advertising, but they assume these variables to be exogenous elements. The models seek for strategies to optimize the cumulative profits without consideration of the highly interdependent influencing elements. Their aim is normative decision support, but they use models, which do not appropriately represent the structural fundamentals of the problem.

The use of the System Dynamics Methodology allows the development of more complex and detailled models to investigate the process of innovation diffusion. These models can enhance the insight in the problem structure and increase understanding of the complexity, the dynamics and the impact of management decisions. But the development of adequate System Dynamics Models requires expert knowledge and plenty of time.

The paper presents an knowledge-based approach to System Dynamics Modelling to shorten the process model building and to make the knowledge about innovation management available for many users. It consists of two parts: A knowledge-based system with the traditional components for dialog, explanation, knowledge representation and inference is used to configure System Dynamics Models, and a modelbase of different modules that represent the generic structures of typical innovation management problems. The knowledge about the innovation problems is included in the different modules and in the knowledge base of the knowledge-based system. In dialog with the user the knowledge based system analyses the problem structure, chooses the relevant modules and finally configures the model that then can be used for further analysis through the problem owner.

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NECESSITY OF DECISION SUPPORT IN INNOVATION MANAGEMENT

Companies can resist to the intensifying competition only by continuous innovation activity. With the increasing globalisation of market and the shorter product life cycles, the importance of a successful introduction of new products is growing in its importance for the enterprises. Innovations offer the chance to gain competitive advantage against competitors, they are however connected with considerable risk because of the very high investments.

Enormous expenditures are made for the development of new product in the R&D phase. Empirical investigations show that R&D expenditures of 100 R&D-intensive German enterprises need in average 8-9 % of the turnover. The phase of market introduction requires immense marketing efforts for the product introduction. In the beginning the innovation phase investments are necessary for sufficient production capacity and establishing sales- and service organizations.

The effects of high investments are opposed by the shorter market cycles of new products and high flop rates. Shorter life cycles of products and production processes are reducing the time span for the enterprise in which they can receive a sufficient payment of interest for the invested capital. In case of a failure there will be no return on investment. Empirical investigations show evidently the risk of the economic success of an innovation. They demonstrated that only each seventh R&D project has come to a commercial success. The failure rates of products that have been introduced to the market have come to 20% to 40 % for investment goods, for consumer goods even to 40 to 80% (Crawford 1979, Cooper 1983).

Therefore it is imperative that instruments for innovation management are available to maximize the chances and to minimize the risks of innovation. For the introductio of new products, however an amazing lack of instruments is apparent that suit the complexity and dynamics of the innovation problems. For decision support the management needs intelligent and flexible instruments that not only are used for the simulation of the decision. Systems are obligatory that promote the understanding of the complex structures as well as the dynamic processes of the innovation activity. Such an integrated decision support system will be presented in this paper.

CONCEPT OF AN INTEGRATED DECISION SUPPORT SYSTEM FOR THE INNOVATION MANAGEMENT

STARTING POINT FOR THE CONCEPT OF THE SYSTEM

Innovation management means target-oriented management of socio-economic systems. The introduction and diffusion of innovations in the market depend on a variety of internal and external effects and their dynamic interactions. An effective control of the diffusion process of a new product is only possible, if the decision process is launched with the knowledge and under consideration of the multiple feedback relations between the system elements. A decision support system for the management of innovation activity has to consider these aspects.

Starting point for the development of a decision support system for the control of diffusion processes is the concept of the product life cycle. Models that are used for decision support must not only describe the life cycle, they also must generate and explain the product life cycle from the interactions of the system elements. The diffusion models discussed in the literature generate the life cycle as a process of quasi natural law character. Partly these models include decision variables to control the diffusion processes, e.g., price or advertising. However these variables are seen as exogenous elements, and they are isolated from the influencing factors of a company. These models are an inadmissible and faulty description of reality. Especially pricing and advertising decisions can not be seen as independent of costs. Costs again depend on the quantity of products sold, which again is influenced by the pricing and advertising strategy. Competition, lead time and many other factors are also to be considered in models that properly describe the problems of innovation activity.

Innovation management requires models that consider the complex structures of the problem. They must reflect all the management decision variables, as well as the structures of the companies, the markets and the interrelations of customers. Different policies of the management and parameter sets must be simulated and analyzed in their effect on the diffusion of a new product. Simulation models based on the System Dynamics methodology are suitable instruments with which the adequate models can be developed and analyzed. However, for decision support, models can only be used if they reflect the specific problems. For example, a model of the life cycle of consumer goods with repeat purchases would be different to a model for long lasting investment goods. Different companies often use different policies, strategies and organizational structures. The various market and product types need special models.

These examples make a syndrome of the problem clear. Basically for each specific situation or problem a distinct simulation model is needed. However this requires considerable expenditure for time and costs. Beyond that, qualified staff should be available to program and analyse the models.

In order to simplify the process of model development the concepts of knowledge-based systems and System Dynamics are integrated in a comprehensive decision support system. A knowledge-based system is used to configure different modules of a specific model. A library of modules includes modules for the structures of innovation management problems. This comprehensive integrated decision support system – the DSS "CAIM" (Computer Assisted Innovation Management) – will be shown more detailed in the rest of the paper.

COMPONENTS OF THE INTEGRATED DECISION SUPPORT SYSTEM

For the conception and development of a decision support system the following criteria are of importance (Little 1970):

- Simplicity in structure and use.
- Robustness relative to the model results.
- Simplicity of control.
- Adaptability to changing problem situations.
- Completeness relative to the important aspects of a decision problem.
- Simple ability to communicate with the system.

The acceptance of a decision support system depends on the ability of the system to fit these criteria. An integration of knowledge-based systems and System Dynamics models offers special possibilities to meet these requirements. The components of the system will be shown in the following.

Knowledge-based systems – also known as expert systems – are built of different components: (1) An inference engine to draw conclusions, (2) a separated and interchangeable knowledge base with facts and rules of a problem domain, (3) a sophisticated user interface and (4) a facility of explanation and a (5) component of knowledge acquisition. The inference engine is defining how the facts and rules of the knowledge base and the data requested by the dialog with the user, are used to draw conclusions to solve a problem. The problem solving components (inference engine) is mostly independent from the knowledge that is stored in the knowledge bases. Therefore it can also be used in other problem areas if specific knowledge bases are available. The knowledge base includes facts and rules of a narrow problem area. In other words, it contains the problem specific knowledge and case specific data that are similar to those used by a human expert to solve problems and make decisions (Harmon and King 1985, Waterman 1986).

The user interface is needed for the user friendly and problem-oriented communication between the user and the system. It allows menu-driven and natural language dialog as well as graphical displays. A very important part of an expert system is the facility of explanation. The explanation subsystem should explain the behavior of the system, through answering questions of the user. It should explain *why* a question was asked, *how* a conclusion was reached and should also *give general informations* about the background of a question. The upper part of Figure 1 summarizes the components of a knowledge-based system and their linkages.

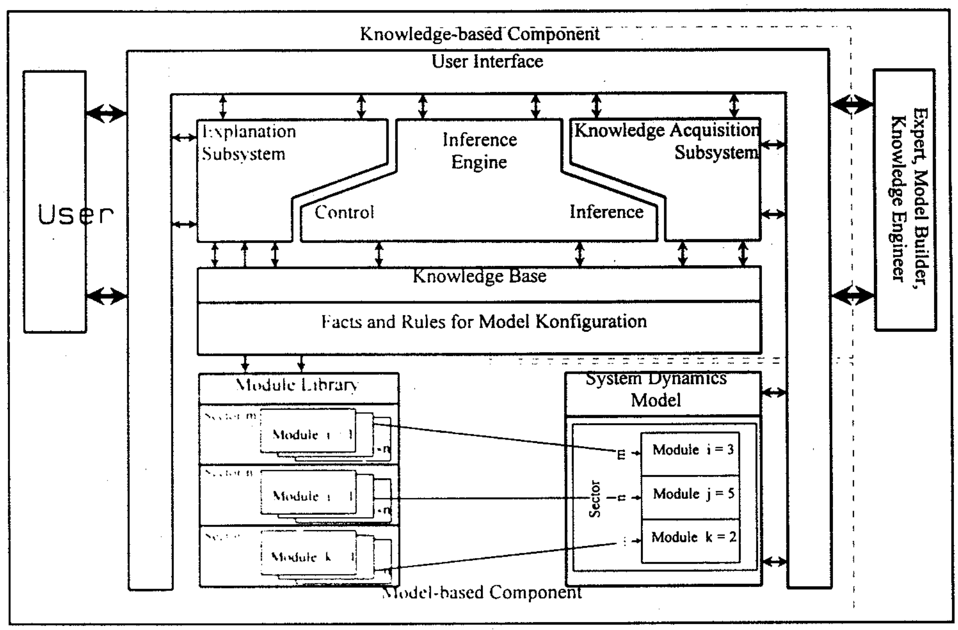

Figure 1: Coarse Structure of the Integrated Decision Support System

The above shown integrated decision support system consists of two main components: (1) the knowledge-based system and (2) a model-based simulation component. An interface program is used to exchange the information between the main components and to control the use of the system. The model-based component includes

- a library of problem specific System Dynamics modules and
- a software package, that is necessary for the simulation – in this case it is Professional Dynamo Plus.

This coarse structure of the system can be interpreted as a generator for specific integrated decision support systems. The specific system "CAIM" includes in the knowledge base the facts and rules, how to configure the different modules to a comprehensive model for supporting innovation management. The module library contains the appropriate modules, that describe the problem structures of introducing new products. In this context there is made a distinct difference between model and module on the one hand and between module library and model library at the other hand. A model, which is divided into different sectors, is the starting point of a simulation experiment. A module characterizes a part of a complete model. For each sector of a model the module library includes special modules that describe different problem structures. A module library consists of specific modules for the sectors of a model, that must be configured to a complete model. In contrast, the model library consists of a plenty of "ready-to-use" models.

The model-builder can develop for the different sectors of a model adequate modules for various problem structures. E.g., for the sector that describes the structure underlying the process of innovation diffusion, it is possible to develop a module for monopolistic, a module for oligopolistic markets and another that considers repeat purchases. However, for problem solving only one of the modules is adequate. This is also valid for all the other sectors of a complete simulation model, like the sector of capacity planning, production or calculation.

There are two arguments for building a library of modules instead of a model library: (1) the required hard disk capacity is much smaller and (2) it is much easier to change the structures of a sector in a module library.

Should for all problem structures – or at least for the most important – an adequate model be at disposal, which is for effective decision support indispensable, one needs a huge amount of "ready-to use" models in the model library. The number of necessary models for building up a model library depends on the number of possible combinations of the sectors of a model and the number of possible problem structures for these sectors. It can be calculated by n^k, where n is the number of different structures and k is the number of sectors of a model. In a situation with n different modules per sector, k sectors of a model, and sectors with a size of bps byte per sector the required hard disk capacity for building a model base with all n^k combinations is:

$$req.\ hd\ cap_{modelbase} = n^k \cdot k \cdot bpm \qquad (1).$$

In the case of a module library there are only $n \cdot k$ combinations of the modules possible. In contrast for bpm byte per module a module base only needs:

$$req.\ hd\ cap_{modulbase} = n \cdot k \cdot bpm \qquad (2).$$

E.g., for $n = 5$, $k = 5$ and $bpm = 1024$ Byte per module a model library needs approximately 16 MB storage capacity. However, a module library only needs 25 KB. For $n = 8$, $k = 5$ and $bpm = 1024$ the required hard disk capacity is 160 MB in the case of a model library and 40 KB in the case of a module library.

Another advantage of a module library consists in easier modifications of the modules of a sector. Only the module that describes the structure to be changed, has to be modified. All other modules and sectors remain unchanged. In the case of a model library all the models have to be modified, that represent the specific structure of the sector. Both advantages, the easier handling and the reduced storage capacity recommend the building of a module library. This however requires, that the user is able to configure the individual modules to a complete model.

Here, the knowledge-based component of the integrated system can offer support. The knowledge-based component of an integrated decision support system has the task to clarify by dialog with the user, which of the different modules describe the structure of the problem adequately. In a knowledge-based decision support system, it is of high importance to have a user friendly design of the dialog interface and a high-quality comprehensive module library. Creativity can be enhanced through the dialog with the system. Learning can be induced and promoted by a well-designed explanation subsystem, the process of model configūration and by the simulation and analysis of the complete model. The use of an integrated decision support system simplifies the process of model building, without getting models with black-box character.

MODULE LIBRARY AND KNOWLEDGE BASE OF THE INTEGRATED DECISION SUPPORT SYSTEM "CAIM"

Effective decision support in innovation management needs models that represent the structures of the markets as well as the structures and policies of the companies. Therefore, it is obvious to divide a complete innovation management model in two parts: (1) a part of the model, which maps the market structure and (2) a part, which fits to the structure of the companies. Additionally the model needs the parameter, initial value and the control statements. The coarse structure of a complete model and the interactions between the different sectors are shown in Figure 2. It also shows, that the corporate part of the model at least should be divided into the sectors of capacity planning and production, the sector of cost planning and accounting, the sector of pricing strategies and the very important sector of corporate control variables of the diffusion process.

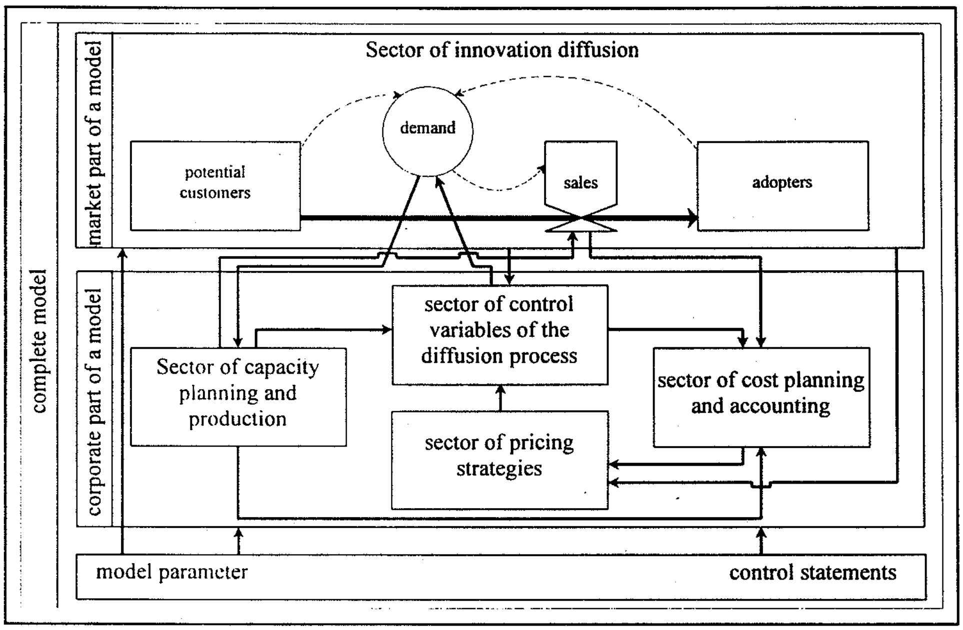

Figure 2: Coarse Structure of an Innovation Management Model

The sector of innovation diffusion includes a diffusion model similar to the Bass model (Bass 1969) or the corresponding System Dynamics model developed by Milling (Milling 1986). The diffusion process is generated through the interactions of potential customers and the adopters, the latter are persons that already bought a product. The sector of control variables defines the effect of a company's marketing mix – such as pricing or advertizing strategies and delivery delays – and the specific competitive situation for the sales of a product. The sector of capacity planning and production comprises the equations for sales forecasting, capacity expansion or reduction, production and among others the delivery delays. In the sector of cost planning and accounting the costs of a product, the monthly cost of a company, the turnover and the profits are computed. Dependent on the pricing policy of a company and the standard costs of a product, prices are calculated. These equations are comprised in the sector of pricing strategies. The necessary model parameter and control statements of the model are defined in a separated sector.

Using this coarse structure of a complete model, for each sector different modules were developed, that represent the specific problem structures. The modules are classified using the criteria of market structure and number of product life cycles to be generated in a model. Four different groups of modules can be distinguished: modules for (1) monopolistic markets and only one product form, (2) monopolistic markets and multiple product forms, (3) oligopolistic markets and just one product form and (4) oligopolistic markets and multiple products forms. Figure 3 shows the structure of the module library and the number and name of the specific modules for each sector. It should be noted that only the modules of the same group fit together and therefore can be configured to a complete model for decision support in innovation management. All modules are programmed using Professional Dynamo Plus.

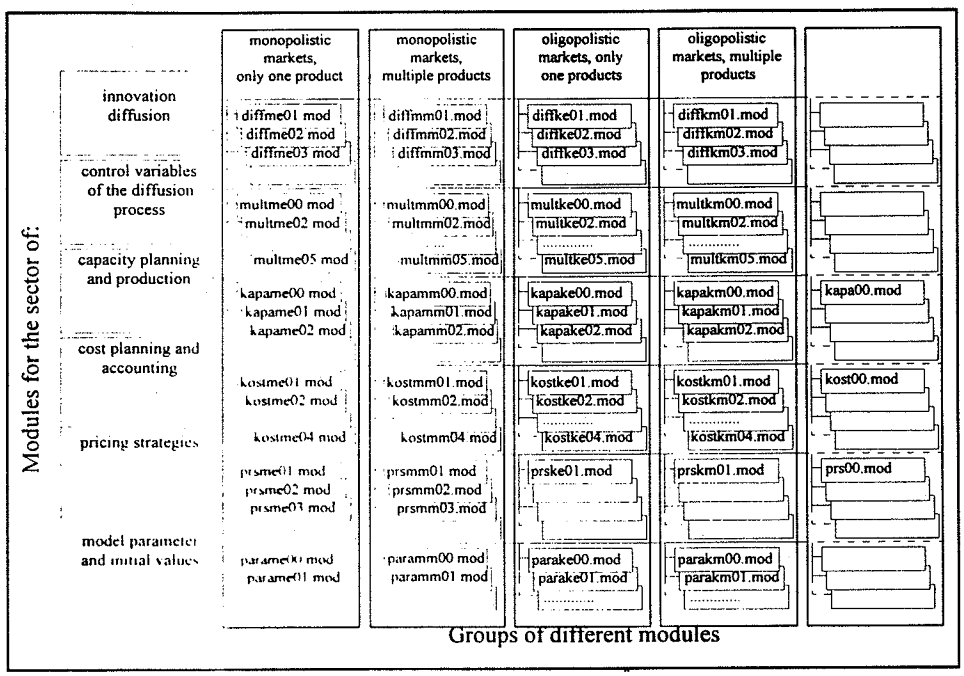

Figure 3: Structure of the Module Library

The knowledge-based component of the integrated decision support system "CAIM" – that is programmed using the fifth generation language Turbo Prolog – has the task to find out which structure characterizes the user's problem situation and which modules adequately represent the problem. However, the interface of CAIM is not only used to configure the models, it is also possible to compile and simulate the complete model and to get graphical display of the simulation results using the appropriate programs of Professional Dynamo Plus.

The structure of an exemplary rule and question for the choice of a module is shown in Figure 4. A rule consists of six arguments (1) one, the rule number, (2) the name of the sector, (3) the name of the module, (4) the information which questions should be asked, (5) how the questions should be answered to verify the rule and (6) the name of the file where detailed information on the module is given. The conditions, which are proofed consist of the condition number, the question to be asked and the possible answers to the questions

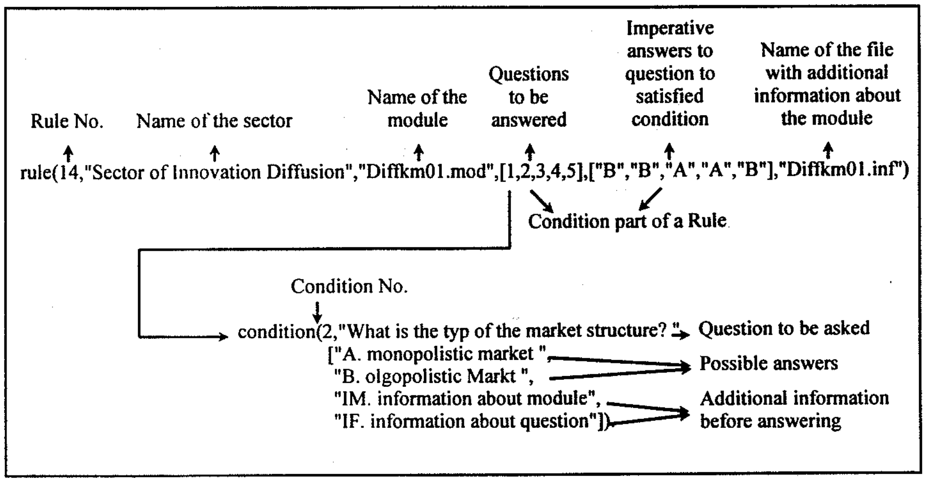

Figure 4: Structure of Rules and Questions

In natural language the rule can be interpreted as follows:

According to rule no. 14, the adequate module for the sector of innovation diffusion is the module with the DOS-file name "diffkm01.mod",
if the conditions
no. 1, that configure a complete model shall be configured and
no. 2, that the market structure is oligopolistic and
no. 3, that capacity restrictions shall not be considered and
no. 4, that there will be no repeat purchases and
no. 5, that the life cycles of muliple products shall be generated,
are satisfied.

The knowledge base includes rules for all the modules of the module library. Through the dialog with the user, "CAIM" proofs the rules, asks the relevant questions and checks the answers. If an answer leads to the failure of a rule the next rule will be proofed. During the dialog with the system the user can get supplementary information about the module that is proofed and the background of the questions. If all rules are proofed the problem structure is clear and the complete model can be configured. Additionally a file is generated which contains a detailed discussion of the model equations and can be displayed and printed. The possibility, that the user can ask for informations about the background of the question and can get a description of the model allows the use of "CAIM" as a learning environment. Therefore, the learning goes beyond the learning through the work with a "ready-to-use" model, because the system explains the problem structures in detail.

After the configuration, the model can be compiled and simulated. Parameter changes, specific strategies or scenarios can be tested and analyzed. The traditional simulation of models and the process of analyzing and improving the model starts.

EXEMPLARY USE OF THE SYSTEM

In the following a short example of the behavior of a model configured using the system "CAIM" will be described. It is assumed that a decision maker of company 1 wants to introduce a new product into the market. The company and three other competitors are already present in the market with one product. For this product typ all competitors have a nearly equivalent market share in terms of the market. He seeks for adequate strategies for market entry time or pricing and wants to know, how the company's sales of the new product, the total sales and cumulative profits of the company develop over time. Furthermore it is postulated that company 1 enters the market in period 18 with an advantage of 6 months compared to the competitors. Firm 1 sells the products with a skimming price strategy, however, the competitors offer their products with a relatively low penetration price. Costs will follow a 80% experience curve; the price elasticity of demand is known and should be considered.

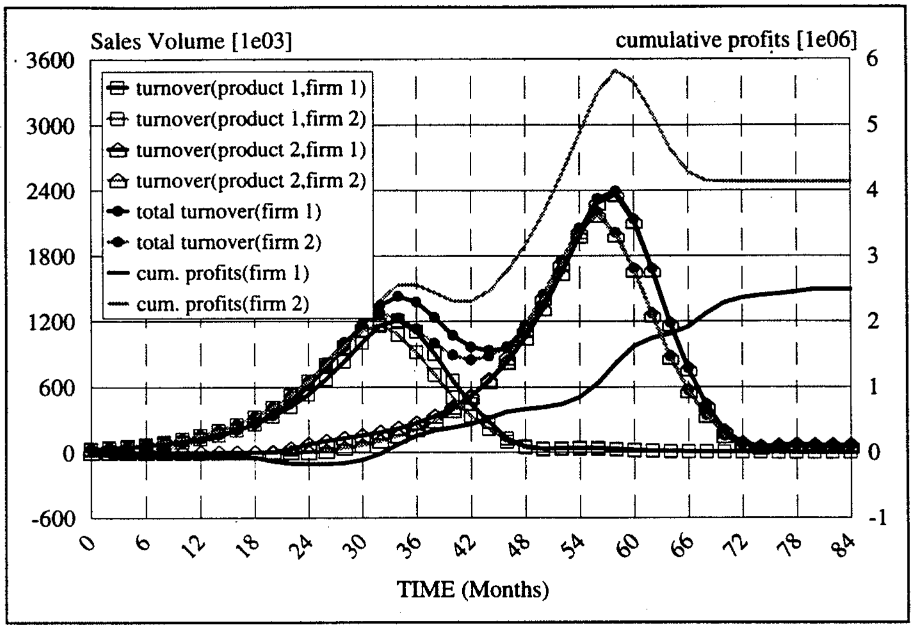

Figure 5: Exemplary Model Behavior

Since the problem owner has used "CAIM" to configure, compile and simulate a model, that adequately represents the problem structure, he will generate the above shown model behavior. Figure 5 shows the time path of the variables, turnover of a product, the company's total turnover and the cumulative profits as an example for firm 1 and one of the competitors .

Although firm 1 introduces its second product 6 months earlier than the competitors and has – due to the skimming price strategy – a higher profit margin, the cumulative profits are shaping worse than the opponent's. A detailed analysis shows as reason the insufficient capacity utilization of the first company resulting in lower profits and even losses until period 32. The initial advantage of firm 1, regarding the turnover of the second product, is made up by the competitors due to their lower prices and the resulting higher demand. This causes a higher capacity utilization rate of the competitors and improved monthly and cumulative profits.

On the basis of the model the decision maker now can test the alternative strategies for market entry time, advertising or pricing, to improve the behavior of firm 1. Simulating and analyzing the model, he can get improved insight into the complex and dynamic problem structure.

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