Model-Based Planning for Strategic Management: An Integrated Simulation and Learning Toolkit

Erich Zahn
Jürgen Greschner

Betriebswirtschaftliches Institut
Universität Stuttgart
Keplerstr.17, W-7000 Stuttgart 1, Germany

ABSTRACT

In a world of increasing complexity and turbulence organizations run the risk to loose effectiveness as well as efficiency when managed on the base of linear thinking and shortsighted decision making. System thinking and organizational learning instead will become a prerequisite for competitiveness and survival.
In our paper we propose an "integrated simulation-learning toolkit" to support strategic decisions in the field of flexible assembly systems.
With the help of this toolkit the user will be led through a structured modelling process in which he will develop his specific managerial microworld. Starting from a generic model the user follows different stages of abstraction and specification.

THE CHALLENGE FOR STRATEGIC MANAGEMENT

The main goal of strategic management is to insure the competitiveness of companies and with it their long term chances for survival. In this context, it is important to keep in mind that companies must operate within a complex environment. The structure of cause and effect in this operational environment has grown more complicated. It is changing constantly, making a shift to conditions difficult to comprehend. This circumstance can be observed in the surprisingly rapid transformation in demands of the market, changes which make it necessary for companies to develop new capabilities and resources continually.
Until now, the perception of complexity in management was largely distinguished by a reductionist method: to make a major problem comprehensible, it would be seen in terms of a conglomeration of smaller problems. The integration of the resulting individual solutions was assumed to then benefit the whole system. Astonishment is great, because this principle frequently does not function in a system of advancing complexity - instead of total optimization, the result was a collection of less than optimal and often conflicting solutions. Slowly but surely the realization is becoming more widespread that a more promising method for the management of complex problems lies in the simultaneous assessment of the whole system.
It would be too much to expect of normal powers of comprehension, however, to observe all the variables in a complex system at once. The management of complexity requires the ability to distinguish between the important and the trivial and to act accordingly.
Since priorities change from day to day, this must be a continual process. For the effects to be long term, planning cannot be a sporadically undertaken procedure; it must be seen as an constant learning process (de Geus 1988).
This view leads to a shift in paradigms in management characterized by changes

* away from mechanistic thinking in linear causality to a more complete view of things, including consideration of feed-back;
* away from planning as a deterministic construction to the view of planning as learning;
* away from a static understanding of strategy as manifested in positions of product/market combinations to a dynamic understanding of strategy as the expression of business behavior.

According to Senge (1992) strategic managers "must become system thinkers as well as better learners".
Until now, in business practice only a few tools exist that make it possible to experience complex systems and train decision making techniques in a simulated environment (Zahn 1991). In a world of turbulent change, policies need to be examined more critically and frequently modified to conform to changed conditions. This implies, however, that the mental models of top management must first be altered and improved (Forrester 1992). In such a complex world CEO's are demanded in their role as "corporate designers" (Forrester 1992). Only by rethinking the logic of cause and effect will they be able to effectively reengineer business and open the door for a strategic renaissance of their companies (Zahn 1993).

Rethinking at the level of top management alone is not enough. For total re-orientation, employees on all levels must join in. As Ferdinand Piëch recently pointed out at a meeting of German executives:

> "Most European businesses today - and this includes VW - are expedient partnerships (Zweckgemeinschaften). They are characterized by management that tries to convey its wishes to its employees and expects those wishes to be understood. As you well know, this concept of management is singularly unsuccessful." (Piëch 1993)

Apart from mere lip-service, the realization that the mobilization of knowledge on all levels of a company is necessary to survive in international competition is gradually being accepted - at least in Germany. With the new slogan "diagonal communication", German companies are trying to promote discussion between participating employees through all levels of company hierarchy and utilize the entire pool of available knowledge to shape the future. It is not the strategic managers that produce the added value of a company but the employees on the operative level. In the past, this available knowledge was not used enough in shaping policy. The pool of knowledge must also be expanded in the opposite direction. Employees on the operative level must understand the strategic dimension of their performance in order to follow the strategic vision of the company. In and between all levels of hierarchy in a company, the reciprocal exchange of knowledge should guarantee that the entire experience of the work force is applied to the solution of problems. Since organizational knowledge is not a static quantity, and given the dynamic of change never can be, constant adaptation and expansion of the basis of knowledge in the sense of organizational learning is necessary. Unrestricted and mutual exchange of knowledge has one basic prerequisite: the mental models of the participants must correspond.

As a result, strategic managers have a further function beyond their individual learning function: they must moderate the collective learning process. In order to do this, they need tools that will enable them to

* view issues in their entirety;
* determine the results of decisions through the inclusion of feedback;
* include all participants;
* compare and contrast the views of participants critically;
* experience difficulties in dealing with complexity;
* regularly identify new critical success factors of business;
* communicate acquired insights;
* and continue to expand the basis of knowledge.

The tools that are based on the system dynamics philosophy have acquired a new topicality in the context of the present discussion.

DEMANDS FOR LEARNING TOOLS

In our opinion, the work with system dynamics tools for decision-making in business has lead to two significant findings:

* Company decision-makers should not only employ finished System-Dynamics-Charts that describe the results of alternative policies, they must use the model actively in order to generate know-how not only know-that.
* Managers must already participate extensively in the modelling process in order to avoid the development of a black box which offers him no help neither in the explanation of the dynamics of his company nor in designing policy-structure.

The formation of the kinds of long term forecast that are used in strategic planning has always been a doubtful undertaking. With increasing complexity and turbulence, long term forecast begin to resemble fortune telling. The probability that long term forecast will actually come true is perhaps 50%. A business that relies on such predictions unquestioningly operates as if decisions for the future could be reached by the flip of a coin. Only through the confrontation with causal and dynamic relationships, for example with the use of learning models or so-called gaming models, can the decision-maker's assessment be sharpened. The work with learning models helps in the perception of dynamics but it will not lead to the comprehensive mobilization of knowledge that can be achieved by the use of system dynamics tools.

As Vennix and Scheper (1990) point out, many system dynamics modelers now see the process of model-building as more important than the output of a validated simulation model. Model-building itself generates basic insights into causal effects of various policies. This more comprehensive knowledge base is frequently only available to the model-builder and is not communicated within the company. In work with gaming models in particular the danger of a video game syndrome exists, in which participating managers have fun playing the game but don't grasp the causal relationships (Senge and Sterman 1990, Kim 1990, Machuca 1991).

The development of explicit learning laboratory concepts take this danger into account. In this case there is no model-builder who presents a validated model after interviews with the managers involved. Instead, the system

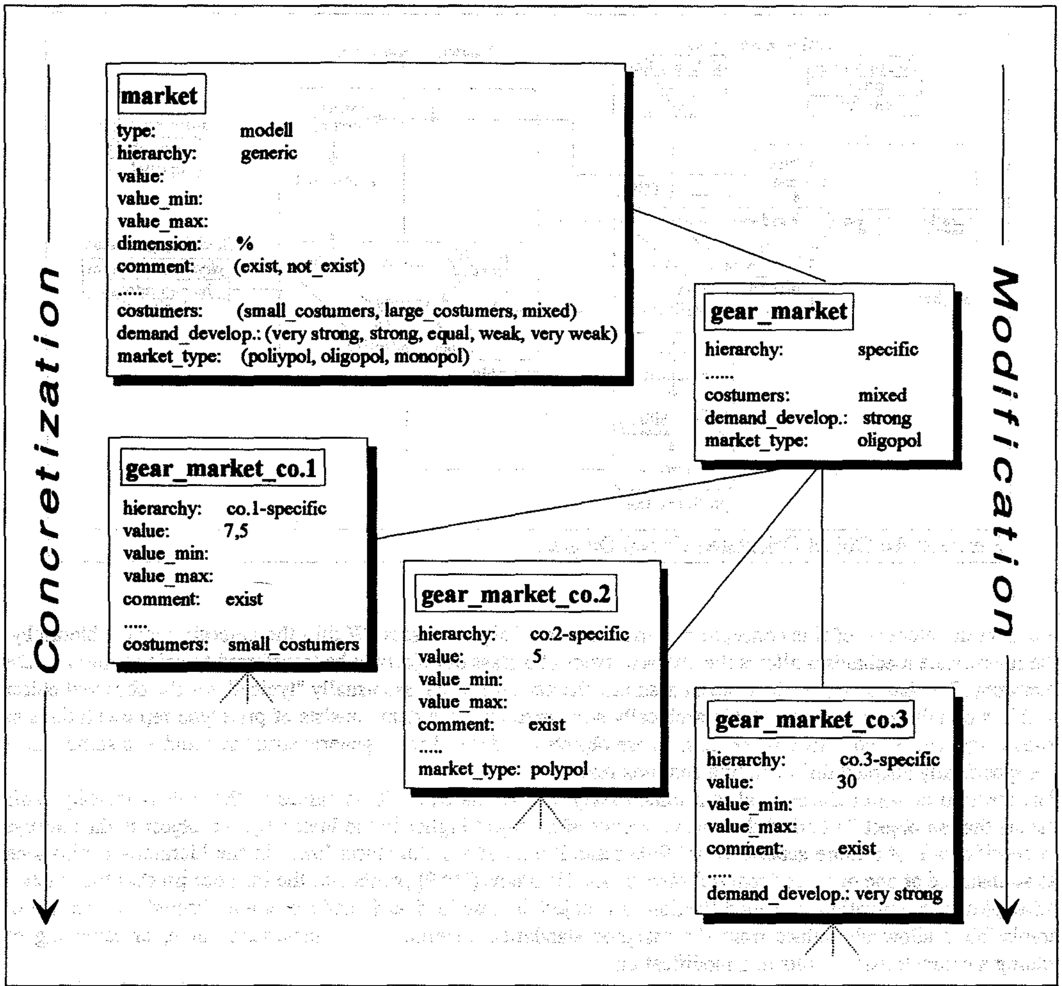

Figure 1: An Object Hierarchy

dynamics expert is the mentor who guides the model-building. The actual model-builders come from the company itself and produce their own simulation or learning models with the mentor's help.
In the rest of this article, we outline our conception for a tool that would allow successive model-building by managers. The prototype of such a tool was developed in a project financed by the Deutsche Forschungsgemeinschaft DFG (Sonderforschungsbereich 158). This integrated simulation and learning toolkit should promote strategic decision-making concerning the design of flexible assembly systems.
The proposed conception is based largely on object oriented programming. In the following sections, we will present the object oriented form of knowledge representation as used in our prototype "Bamboo".

OBJECT ORIENTATED KNOWLEDGE-REPRESENTATION

Object orientated knowledge representation allows a clear description of chosen objects or frames by using their characteristics. Characteristics and procedures are linked to the object in so-called slots. Analogous to the real world, the slots make it possible to save characteristics of a particular object directly within this object. Related knowledge is not divided into pieces and stored at different places. As in reality the object and its characteristics can be found "at the same place" in the model.

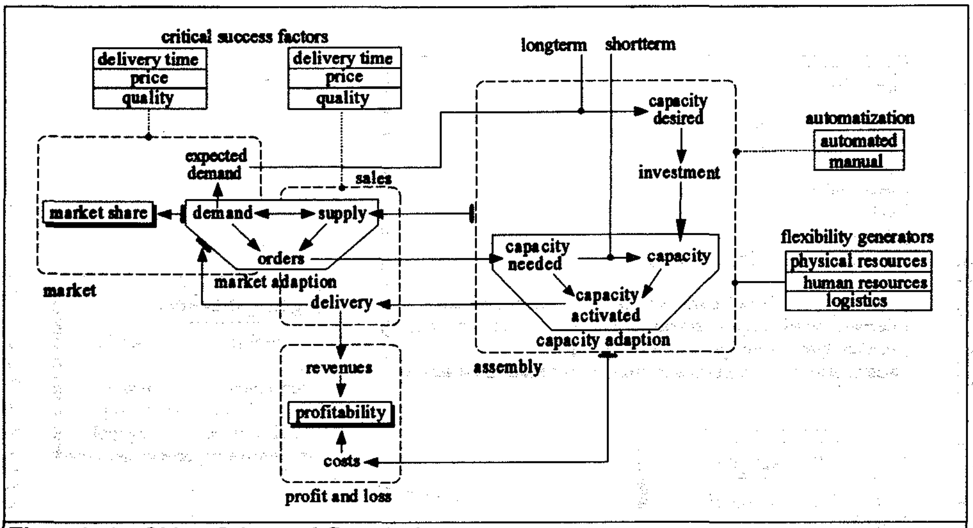

Figure 2: An Object Orientated Causal Diagram

An essential element of this conception is the creation of object classes. Within the emerging object hierarchy, the inheritance mechanism allows the characteristics of a class of objects to be transferred to objects lower in the hierarchy. The basic idea of the concept assumes characteristics that are usually "typical" for the observed object within a certain problem area. A hierarchically structured object system consists of prototype representations of knowledge and of more specific objects. These objects are derived from generic structures and - in some case - are specifically adapted for modelling complex reality.
The creation of object classes makes it unnecessary to save shared attribute values in the slots repeatedly. This means that an object "inherits" the characteristics of an object higher in the hierarchy. An object is thus always "a specification of a more generic class" (Fikes and Kehler 1985). An object lower in the hierarchy is also seen as an instance of one or more "generic" objects. As Kleinhans (1989) points out, the instance process follows two principles: concretization and modification. An object is described and made concrete through the choice of admissible / allowable values from the assigned standards. Changing a characteristic value, or removing or adding a characteristic results in a modification.
The example in figure 1 shows the application of object orientated knowledge representation for a given business context.
The market is the most "generic" object in the hierarchy. On this level, the value range of the characteristics for a commonly seen feature in a general market object are determined. These features refer on the one hand to "technical" characteristics that can be observed in every object of the model, such as the type of the object, the hierarchy within the object tree, or the actual value in a simulation. On the other hand, further characteristics of the object that are not present in all the objects of the model can be saved, because they refer to a certain class of objects. In the example in figure 1 objects from the object class "market" are characterized more precisely by characteristics like "customers", "development of demand", and "market type". In addition, every object is given an additional slot, "commentary", that points to the existence of explanatory text on the object. While working with BAMBOO, explanatory text can be called up for interactive use.
In objects that are low on the hierarchy, features are concrete. The subordinate "automotive parts market (gearsystems)" for example is characterized as "oligopol"; "development of demand" is usually described as "strong". Customers can not be clearly identified on this level as "large- or small scale costumers"; the entry is "mixed".
The "automotive parts market (gearsystems)" as an instance of the market inherits all the technical characteristics, since an exact specification can not yet be reached. Only at the next lower instance can more precise determinations be made. These objects refer to three different markets of three companies. Further instances of this object level of companies might be different markets in which the companies are active. In the hierarchical structure of the frame, modelling can be achieved simply by the introduction of new instances; by "hanging" further objects on the object tree.

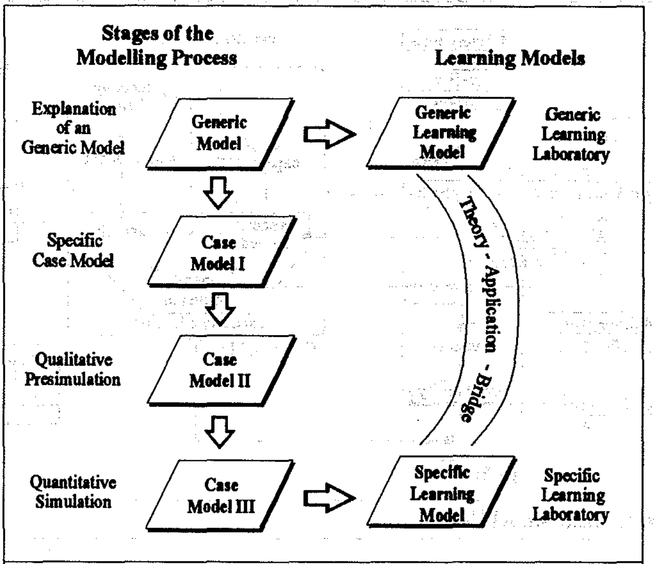

Figure 3: An Integrated Simulation and Learning Toolkit

OBJECT ORIENTATED CAUSAL DIAGRAMS

With this theoretical basis, we developed the object orientated causal diagram. (Zahn et al. 1990, Zahn et al. 1992). An example of an object orientated causal diagram is shown in figure 2. The model on which this diagram is based is meant to be utilized for strategic investment and automation decisions in the assembly work of a selected company.

The complete model is organized into the submodels market, market equilibrium, sales, assembly, use of capacity, and profit and loss. Use of capacity is included complete in the assembly model. The models market, market equilibrium and marketing overlap. The individual models have different characteristics. Market is characterized by strategic success factors: time, price, quality. The examination of the models market and assembly make the principle of inheritance clear. So-called flexibility generators such as physical and human resources, and logistics for example are instances of the assembly model and, as a result, inherit the preexisting model structure that is determined by the elements and relations of the submodel assembly. Actually, there are three assembly models, but with the inheritance mechanism, they need not be displayed individually. The distinction between physical resources, human resources and logistics is made automatically.

FROM GENERIC TO SPECIFIC MODELS

Within the framework of a phase concept as shown in figure 3, the user should be introduced to the simulation step by step and with the help of a computer. In the first phase, the user works with a computer implemented causal diagram of a generic model in which the basic structure of the problem appears in the form of a hypertext net.

Problem cases from the same area of application usually display a similar basic structure. The identification of such basic structures make it possible to create a generic model. Such a structure is similar to all models that are based on a concrete case from the observed area of application (Graham 1988). From an object orientated view of the problem this implies understanding the observed systems of an application as objects and developing a relatively universal object as "generic model". From this object, all other applications can be derived as special cases or instances of object orientated knowledge representation.

The generic model is not as concrete and, as a result, smaller than the concrete case model. Small, uncomplicated models are much better for the first confrontation with the problem. The model-builder first becomes acquainted with the generic model and acquires a basic understanding of the problem.

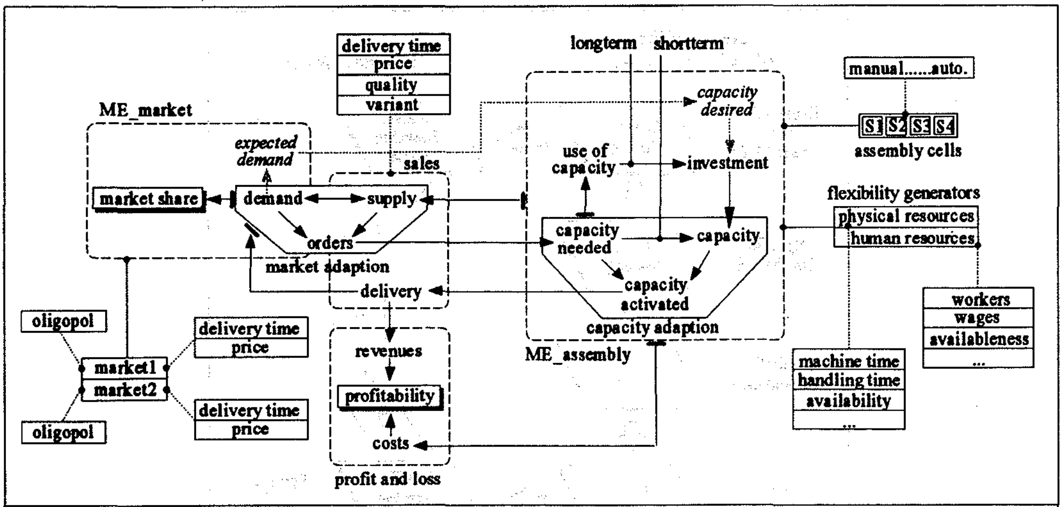

Figure 4: The Concrete Case Model "ME"

With the knowledge provided by the static "structure description model" and the help of a modelling tool, the user can create a generic learning model that makes it possible for him to generate basic knowledge about dynamics in his field of interest. For this purpose, he chooses from available modules and assembles a first learning model that suits best "his" reality on a general level. Archetypes of market development, for example, are available: linear market growth, market development with chance influences, etc.. The purpose of a first learning model is to create a better understanding of basic patterns omnipresent in working with complex systems (shifting the burden, eroding goals, etc. Senge 1990).

Only then does the user create "his" model from the existing, generic structures. The system then makes all functions available that allow him to independently construct an appropriate model for his problem situation.

The simple causal diagram introduced in the preceding section reflects the structure of the generic model implemented in BAMBOO. Clicking on the mouse at the appropriate object gives the user access to all the general information in that problem section and generates a concrete model on the basis of the information and modelling tools.

Output in the second phase is not a functioning simulation model but rather a structurally expanded hypertext system which makes information available to other users of the company.

Figure 4 shows the object orientated causal diagram of the case model "ME". Necessary adaptations and changes specific to the company are recognizable when compared to the generic model:

* In this company, assembly of the products under examination go through four assembly stations that can either be configured in automated or manual way. The object orientated causal diagram contains the structure of the assembly only once. Through the object orientated form of presentation, this structure is "inherited" on all four assembly stations (S1, S2, S3, S4).
* Within the scope of the investigation of the concrete case, two market segments with different products had to be considered - as opposed to the generic model with only one market or market segment. In both of the market segments under consideration, success factors such as delivery time and price determined the market success of the company. The quality of the products was not considered.
* Logistics as flexibility factor was not included in this case study. In order to do justice to the concrete allocation of tasks in a real situation, it was necessary to include both a modification of market structures as well as a detailed description of the specific assembly system. For this reason, the flexibility generators were specified by using production data.

FROM QUALITATIVE PRESIMULATION TO QUANTITATIVE SIMULATION

In the third phase, the user determines the relationships of the model entities (modelled as objects in the system) on the qualitative level. The qualitative specification of the relations includes setting the direction (dir [positive/negative]), the delay (delay [<numerical>]) and the strength of the relationship (force [+/=/-/#]). Possible values for force are increasing (+), constant (=), decreasing (-) or qualitative (#). Moreover, the user has the possibility to store constraints in verbal form that describe the restrictions of relations.

DIR	positive	negative
positive	positive	negative
negative	negative	positive

Link Matrix of Direction

DELAY	min_y -> max_y
min_x	$min_x + max_y$
->	--->
max_x	$max_x + max_y$

Link Matrix of Delay

FORCE	+	-	=	#
+	+	=	+	#
-	=	-	-	#
=	+	-	=	#
#	#	#	#	#

Link Matrix of Force

Figure 5: Link Matrix

Model structures specified in this way allow a qualitative presimulation in advance of the quantitative simulation.
The term "qualitative presimulation" is used to distinguish it from "qualitative simulation" and "qualitative reasoning" as used by Kuipers 1986, Forbes 1984 and Kleer and Brown 1984. The qualitative presimulation in BAMBOO "only" provides a static view of the system. Eberlein et al. (1990) have provided a similar analysis option in their program VENSIM.
An interactive "causal path analysis" which allows to examine all the paths between two important elements of a model concerning for example their direction and delay may help to learn the way how the system works as a whole. A path consists of numerous elements and their relations between two elements. As a rule, numerous paths exist that are combined to make what is referred to as a "set of paths". The same functions exist to examine loops and "set of loops". For strategic decisions where intangible factors play a considerable role such a problem view of decision support may provide decisive insights.
Qualitative knowledge is "contained" explicitly and implicitly in the system. The user can retrieve this information through various functions:

Structure Analysis
The simplest system function generates the description of the objects contained in the model. The object and its slots as well as the text of the commentary-slot are given. The prerequisite for conducting a path analysis is the data on the individual paths in the system concerned, which is difficult to identify without technical help. BAMBOO provides functions to find and analyze these paths. The qualitative effect of a path with regard to the direction (dir), the strength (force) and the delay factor (delay) is determined according to the link matrix in figure 5.

Policy Analysis
The results of the structural analysis are the point of departure for this class of investigations. The paths and loops that have come to light between the elements of a model are combined in so-called sets of paths and sets of loops and can be analyzed as a whole. The major elements "capacity" and "profitability" in case study model "ME" for example are linked by 5 causal paths. Some of the results of this path analysis as generated by BAMBOO are presented in figure 6. All of the paths between the beginning and final elements of the causal chain, as defined by the user, have been investigated by BAMBOO according to the overall effect of the qualitative parameters of influence. These results serve as input for further sensitivity analyses.

Sensitivity Analysis
With the help of this analysis function, the sensitivity of model objects can be determined. In addition, it is possible to discover which restrictions apply to sets of paths and loops.

....						
effects	MEprofitability	negative	0-0	=	*	
Total effect		negative	0.5-0.5	#	!!! constraints !!!	

****

2. Path from MEcapacity to MEprofitability (p_MEE113_MEE19_2)

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		dir	delay	force	constraints
MEcapacity					
effects	MEcapacity_activated	positive	0-0	=	*
effects	MEdelivery	positive	0.5-0.5	=	If there aren't limitations in logistics
effects	MErevenues	positive	0-0	=	*
effects	MEprofitability	positive	0-0	=	*
Total effect		positive	0.5-0.5	=	!!! constraints !!!

****

3. Path from MEcapacity to MEprofitability (p_MEE113_MEE19_3)

****

		dir	delay	force	constraints
MEcapacity					
effects	MEcapacity_activated	positive	0-0	=	*
....					

Figure 6 : Analysis of a Set of Paths

The simplest functions determine the sensitive successor or predecessor of an element with regard to the direction (dir), the strength (force), or the delay function (delay). With a further function, the sensitive relations in a path can be ascertained. These results are automatically saved in objects created during the running of the system.
The critical paths in the sets of paths and loops present a much more complex analysis. For this purpose, BAMBOO implements algorithms that reduce the number of paths between two elements to the most relevant.

Deviation Analysis
Important decision support can be provided by the analysis of structural deviations in the assembly area of one's own company as compared to general structures. The awareness of these deviations can be used as a basis for the identification of strengths and weaknesses of a company compared to its competition, and as such, form an important basis for the development of strategy. In addition, a model management tool allows the change between the generic model and the individual case models shown in BAMBOO. With diversified companies in particular, the figure of different assembly structures with very different market forms makes little sense. However, the immediate accessibility of the data of the generic model as well as the information on various assembly areas of the company makes the comparison of structures and operations of systems possible.

In the next stage of conception the user defines quantitative functions for individual model objects and transfers the model in a further phase in a new condition. In the fourth phase, the usual user-friendly functions of a System Dynamics quantitative simulation are available to the user.
At any time during the work with the quantitative model, the user has the option of returning to the qualitative level and using the available analysis schemes to better understand the output of his quantitative simulation.
The preliminary conclusion of the model building is the conversion of the validated simulation model with the help of a toolkit into a specific learning model. This managerial microworld can then be used in the company as a tool of organizational learning. The users of this micorworld can refer to the qualitative components of the system at any time and investigate the causal structure of the model using the analysis functions described above.

An essential element of the use of the tools is the discovery of correlations that have remained hidden. New model building on a regular basis is an important part of a continuing learning process. In this way, the danger of believing in a supposedly definitive picture of reality and confusing this illusion with the real world is averted.

REFERENCES

De Kleer, J. and Brown, J.S. 1984 : A Qualitative Physics Based on Confluences. In: Artificial Intelligence, 24, 1984: 7-83.

De Geus, A. (1988): Planning as learning. In: Harvard Business Review, March-April: 70-74

Eberlein, R.C., Peterson, D.W. and Wood, W.F.: One Technical Solution to the Modeling Dilemma. In: Proceedings of the 1990 International Conference of the System Dynamics Society, Boston: 341-354.

Fikes, R. and Kehler, T. 1985: The Role of Frame-Based Representation in Reasoning. In: Communications of the ACM, 28, 1985, 9: 904-920.

Forbus, K.D. 1984: Qualitatice Process Theory. In: Artificial Intelligence, 24, 1984: 85-168.

Forrester, J.W. 1992: The CEO as a organization designer - An interview with Professor Jay W. Forrester from Keough, M. and Doman, A. In: The McKinsey Quarterly, 1992, 2: 3-30.

Graham, A.K. 1988: Generic Models as a Basis for Computer-Based Case Studies. In: Proceedings of the 1988 International Conference of the System Dynamics Society, La Jolle: 133-147.

Kleinhans, A.M. 1989: Wissensverarbeitung im Management, Frankfurt et al.

Kuipers, B. 1986: Qualitative Simulation. In: Artificial Intelligence, 29, 1986, 3: 289-328.

Machuca, J.A.D. 1991: When creating and using games, are we neglecting the essential of system dynamics ? In: Proceedings of the 1991 International Conference of the System Dynamics Society, Bangkok: 329-335.

Piëch, F. 1993: Was Piëch zu sagen hat. In: Mannheimer Morgen, 1th April 1993: 9

Senge, P.M. 1990: The Fifth Discipline, New York et al.

Senge, P.M. and Sterman, D. 1992: System thinking and oganizational learning: Acting locally and thinking globally in the organization of the future. In: European Journal of Operational Research 59, 1992: 137-150.

Vennix, J.A.M. and Scheper, W.J. 1990: Modeling as organizational learning: an empirical perspective. In: Proceedings of the 1990 International Conference of the System Dynamics Society, Boston: 1199-1210.

Zahn, E., Foschiani, S. and Kleinhans, A.M. 1990: Strategieunterstützungsmodelle in der Produktion. In: Zahn, E. (ed.): Organisationsstrategie und Produktion, München: 113-150.

Zahn, E. 1991: Strategieunterstützungssysteme. In: Milling, P. (ed.): Systemmanagement und Managementunterstützungssysteme, Berlin 1991: 43-79.

Zahn, E., Foschiani, S. and Greschner, J. 1992: Systeme zur strategischen Planung von Produktionssystemen. In: VDI-Z, 6, 1992: 32-39.

Zahn, E. 1993: Die strategische Renaissance des Unternehmens. In: Zahn, E. (ed.): Fit machen für den Wettbewerb. Stuttgart: 1-44