Cognitive tools for dynamic analysis of enterprise business strategies[1]

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Abstract

The article discusses the difficulties of long-term dynamic analysis of business strategies of enterprises in present-day complex and unstable economic conditions. We discuss the possibility of solving the problem by means of cognitive modeling, which has opened a new page in the management of complex systems and complex problem situations. We note the phenomenological features of complex systems and complex problem situations that exclude the possibility of their modeling using traditional economic and mathematical methods. Such features are: multifactority, dynamism, uncertainty, the high role of the mentality of the developers of the strategy and the persons making strategic decisions. The urgency of the question of ensuring the reliability of cognitive models, a significant place in which is occupied by heuristic components, is emphasized. Formalization of the latter encounters numerous difficulties ("traps") that arise at all stages of designing cognitive models – the stages of identification, conceptualization, formalization and testing, which constitute the specifics of the development of all knowledge-based support technologies.

Existing methods and models from relevant areas that can be useful for overcoming these difficulties are considered (strategic analysis, strategic planning, scenario analysis, scenario planning,

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SWOT analysis, PEST analysis, SMART technology, methods of knowledge identification, methods of psycho semantics and non-metric multidimensional scaling, methods of expert evaluation).

The article presents a demo version of cognitive tools for dynamic analysis of strategies (cognitive map of strategy and cognitive map analysis methods), based on the ideology of cognitive modeling. Consideration is given to the application possibilities of cognitive tools in the analysis of strategies in the context of possible dynamics of the internal and external environment of the enterprise. An example of the use of cognitive tools is given.

Key words: enterprise business strategy, dynamic analysis, cognitive modeling, cognitive tools.

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Introduction

One of the most challenging problems for a management team engaged in formulating an enterprise's development strategy is understanding the complex causal chains that determine the impact of the enterprise's external and internal conditions on the goals and properties of the strategy being formulated. These days this problem is aggravated by the growing complexity and instability of the economic environment, resulting in numerous uncertainties and risks.

In these conditions, the use of known strategic management support tools, such as Total Quality Management (TQM), Business Process Reengineering (BPR), Balanced Scorecard (BSC), Six Sigma, Business Performance Management (BPM), Business Intelligence (BI), Decision Support Systems (DSS), strategic planning systems, etc. is universally accompanied by serious difficulties and constraints. There is a need for new tools that would be relevant to the creative nature of today's management [1] and based on the research approach and long-term dynamic analysis of strategic decisions under different future development scenarios.

Ideas and methods of cognitive modeling presented, for instance, in [2, 3], as well as in the proceedings of International Conferences on Cognitive Modeling (ICCM) Series[1] offer many opportunities to create such tools.

The key principles of cognitive modeling are described further below, and its basic ontologies – cognitive maps and methods for analyzing cognitive maps – are considered. We give examples of the use of cognitive management elements as management consulting tools and discuss their application possibilities. We also present cognitive tools for dynamic analysis of strategies that take into account the peculiarities of the enterprises' activity in current difficult conditions. These tools can be used to find effective (in one sense or another) strategies in the face of an ever-changing business environment. An example of the application of these tools is given and their application possibilities are discussed.

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1. Key principles of cognitive modeling

Cognitive modeling is a method of analyzing and managing complex (ill-structured [4]) systems and problem situations implemented through:

a) building a model of a problem situation in the form of a cognitive map;

b) conducting model experiments in order to find effective strategies for managing the problem situation which are implemented using cognitive map analysis methods.

1.1. Cognitive map

A cognitive map [5] is a formalized representation of management subjects' mental models [6] of the structure of the problem situation and the patterns of its functioning and development. A cognitive map is a causal network, the vertices of which are the basic factors of the problem situation and the arcs are the cause-and-effect relations between these factors.

In terms of content, basic factors are the factors that define and confine observable phenomena and processes of the situation and are interpreted by management subjects as essential, key parameters of those phenomena and processes.

A common representation of a cognitive map these days is a directed graph (X, W), where $X=\{x_i\}$ is the set of the basic factors of the problem situation; $W = \{w_{ij}\}$, $w_{ij} \in [-1; +1]$ is the set of the cause-and-effect relations that determine the sign and intensity of impact of casual factors on effectual factors.

The ordered set of linguistic values Z_i and a scale representing those values at a point of the number line, $\varphi: Z_i \to Z_i \to X_i$, are determined for the factor x_i.

The factors can be external environmental factors, target factors of a problem situation, controllable and uncontrollable factors of the situation itself. By manipulating controllable factors, one can take the situation from some initial state to the target state.

1.2. Cognitive map analysis methods

Cognitive map analysis methods make it possible to carry out model experiments on the cognitive map by changing the composition and values of the basic factors and the nature of the cause-and-effect relations between them. Such model experiments allow us to investigate the spread of external impacts and control actions across the cognitive map and solve a wide range of tasks related to determining priority management decisions, assessing the attainability of management objectives, formulating alternative management strategies, finding effective (in one sense or another) management strategies, etc.

Existing methods of cognitive map analysis are focused on problems of static and dynamic types of analysis. Static analysis, or impact analysis, is a range of objectives aimed at studying the structure of mutual interaction of the factors of a cognitive map. Dynamic analysis underlies the generation and analysis of possible scenarios for situation development in time in the modes of "self-development" and "controlled development."

The theory of dynamic analysis of cognitive maps is based on the apparatus of linear dynamic systems [5]. Dynamics are simulated by setting successive impulse actions on controlled factors (causal factors) at discrete instants of time $t = 0, 1, 2, \ldots$ and by modeling the influence wave of these impacts on the target factors (effectual factors).

A control action on the situation is set by an impulse change in the value of the controlled factor $x_{in} \in X_i$.

The variation of the values of effectual factors is determined by the "rule of the impulse process":

$$x_i(t_0+1) = x_i(t_0) + \sum_{i \in I} \text{sgn}(x_j, x_i)\, w_{ij}\, \Delta x_j(t),$$

where $x_i(t_0)$ – the value of the i-th factor at the instant t_0 before the control action;

$x_i(t_0+1)$ – the value of the i-th factor after the control action at the instant (t_0+1);

$$\text{sgn}(x_j, x_i) = \begin{cases} +w(x_j, x_i), \textit{ if the arc } (x_j, x_i) \textit{ is positive}, \\ -w(x_j, x_i), \textit{ if the arc } (x_j, x_i) \textit{ is negative}, \\ 0, \textit{ if the arc } (x_j, x_i) \textit{ is absent}. \end{cases}$$

$\Delta x_j(t_0)$ – the impulse increment of the j-th control action at the instant t_0;

w_{ij} – the weight (force) of the impact of the factor x_j on the factor x_i;

I_i – the number of factors that have a direct impact on the factor x_i.

Thus, the value of the effectual factor at any instant is estimated as the sum of the values of the factor at the previous instant and all the impacts that came from neighboring (associated) factors. In evaluating the resultant value of a factor, both the actual values of the influencing factors and the degree of their impact are taken into account.

In dynamic simulation, along with the values of factors, variation trends of those factors can also be used. A situation development forecast is obtained in the form of vectors of the situation state at successive discrete instants of time t, $t+1$, ..., $t+n$, where t is the number of the simulation step (time-step).

The objective of situation management consists in taking the situation from the initial state to the target state corresponding to the target image of the problem situation.

The target image determines the desired changes in the state of the problem situation from the perspective of management subjects and is formally represented as

$$C = (X^C, R(X^C)),$$

where X^C – the set of target factors that are the subset of the basic factors of the cognitive map $(X^C \subseteq X)$;

$R(X^C)$ – the vector of the estimates of the dynamics of the target factors establishing the desired changes in these factors, e.g.,

$$R(x(t)) = \begin{cases} +0,7, \textit{ if a SIGNIFICANT growth} \\ \quad \textit{of the factor } x_t \textit{ is desired}, \\ 0, \textit{ if stabilization of the factor } x_t \textit{ is desired}, \\ -0,3, \textit{ if an INSIGNIFICANT growth} \\ \quad \textit{of the factor } x_t \textit{ is desired} \end{cases}$$

Problem situation management strategy S consists of the strategic moves S_i, that determine the sequence of the transition of the situation from the initial state S^0 to the target state S^C corresponding to the target image

$$S: S^0 \to S^1 \to S^2 \ldots \to S^C.$$

Application versions of dynamic analysis models and, in particular, models of dynamic analysis of the enterprise's strategies, require clarification of the concept of "strategic move."

Any strategic move is an act that changes the state of the situation. A change in the situation at every step can be accomplished by means of the operators listed in *Table 1*. Note that the list of operators for sign cognitive maps (SCM), in which only the signs of mutual interaction are specified, differs from that for weighted cognitive maps (WCM), in which both the sign and the force of mutual interaction are specified.

Using these operators, management subjects can design a variety of strategic alternatives that reflect different scenarios of problem situation development.

Once a fixed set of strategic alternatives is determined, it is possible to clarify the statement of the strategy choice problem. It can have different formulations and, accordingly, different configurations of the target image of the problem situation.

Table 1.

Operators of a strategic move

Operators	CM type	
	WCM	SCM
1. Changing the value of a controlled vertex at a given time	●	
2. Adding a new vertex and new arcs to and from it at a given time	●	●
3. Changing the sign of an arc at a given time	●	●
4. Changing the weight of an arc at a given time	●	
5. Adding a new arc between the existing vertices	●	●
6. Adding a new circuit (increasing or decreasing the deviation)	●	●

We shall give several examples of the statement of a strategy choice problem.

1. Finding the optimal (shortest, cheapest, etc.) strategy that meets the regulatory constraints on some parameters of the enterprise's internal or external environment;

2. Finding a strategy that maximizes (minimizes) the values of some vertices (for example, enterprise profits, market share, product quality, environmental pollution, etc.) subject to restrictions on the values of some other vertices (e.g. financial resources, time constraints, staff qualifications, etc.);

3. Finding a strategy that does not allow any of the enterprise's variables to take too large or too small values (the so-called "dynamically stable" or "stabilizing" strategies).

The process of strategy building ends when a satisfactory result is obtained, which consists in achieving a state corresponding to the target image of the controlled situation under the given constraints.

However, there is also the possibility of failure in achieving the target image resulting in the need to return to the stage of formation of the target image (revision of the "mission-goal" transition) or complete abandonment of further search.

2. Dynamic analysis of enterprise strategy

Let us consider the possibilities of using the cognitive modeling technology in dynamic analysis of an enterprise's strategy.

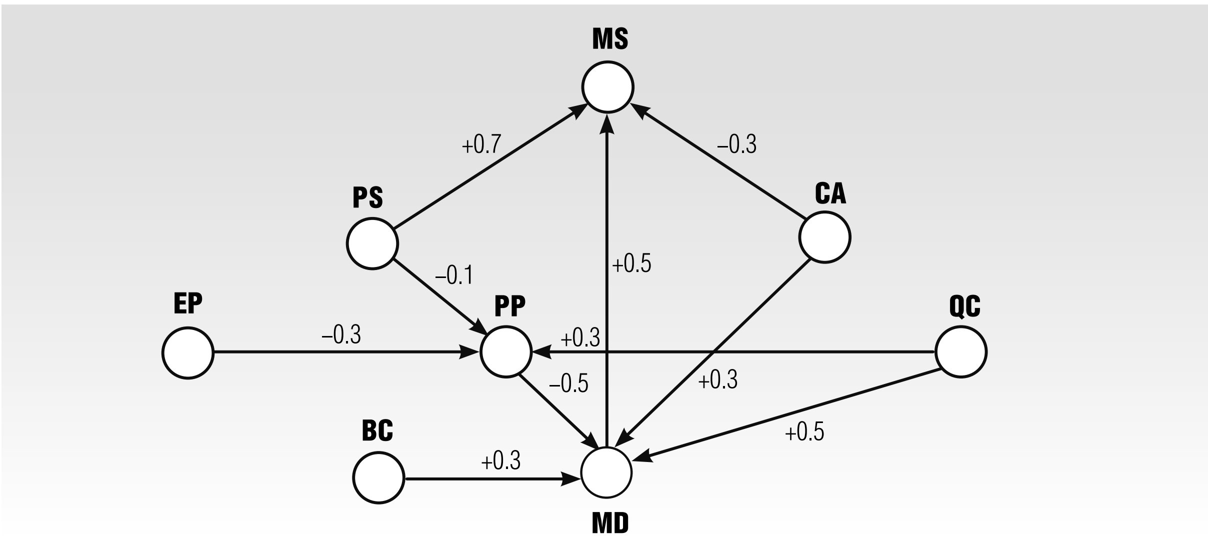

Fig. 1. Cognitive map for the enterprise's customer relations management strategy analysis (demo version)

We shall take as our example the cognitive map (*Figure 1*) built for analyzing a customer relations management strategy (the "client" level of Kaplan and Norton's strategy map [7]). A weighted cognitive map is used.

The basic factors of the cognitive map are:

- "Product competitiveness" (PC);
- "Enterprise's productivity" (EP);
- "Business conditions" (BC);
- "Market demand" (MD);
- "Product price" (PP);
- "Market share" (MS);
- "Quality control" (QC);
- "Competition's advertising" (CA).

On the set of basic factors, we have:

- target factors: <MS, PP>;
- controllable factors: <PC, QC, EP>;
- factors of external environment: <BC, CA, MD>.

This breakdown of factors allows us to conduct a wide range of model experiments, e.g.:

1) designing different strategy variants, including the enterprise's "self-development" strategy and various "controlled development" strategies;

2) forecasting the enterprise's behavior (its target image) for each of the strategy variants;

3) forecasting the enterprise's behavior (its target image) under different dynamics of factors (different development scenarios) of external environment, etc.

Let us illustrate this with the results of model experiments with the strategy variant given in *Figure 1*. We shall investigate the strategy dynamics for different initial states (activity levels) of the factors.

The activity levels of the factors and the intensity of their interaction will be estimated using the linguistic scale given in *Table 2*.

Table 2.

Linguistic scale for estimating the values and the intensity of interaction of factors of a cognitive map

X	Linguistic estimates (*Z*)
0.1	VERY_LOW | VERY_POOR | VERY_WEAK
0.3	LOW | POOR | WEAK
0.5	AVERAGE | MODERATE
0.7	HIGH | GOOD | STRONG
0.9	VERY_HIGH | VERY_GOOD | VERY_STRONG

Note the following:

1. For the factors that can be estimated quantitatively, each linguistic estimate is put in correspondence with the value of a factor from the "interval scale", e.g.: "Market share" VERY_LOW – below 4%, LOW – 5–10%, AVERAGE – 11–20%, HIGH – 21–40%, VERY_HIGH – over 40%.

2. The values of the factors and the characteristics of interfactorial relations are set for a specific enterprise and for a specific period of time (horizon of analysis).

Example. Assume that the management goal in the strategy fragment in *Figure 1* is to find and implement such management (changing the controllable factors) that would lead to an increase in the enterprise's "Market share." The possibility of achieving this goal is affected by:

1) the initial state of the internal and external factors forming the analyzed strategy fragment;

2) the management implemented by the enterprise's management team through changes in the dynamics of the controllable factors.

Scenario. Assume that the enterprise introduces a new product to the market, i.e. its "Market share" at the initial moment of time is almost imperceptible: MS = 0.1 (VERY_LOW). The enterprise introduces a new product to the market in stable economic conditions: BC = 0.9 (VERY_GOOD). These conditions create a high demand for the product: MD = 0.7 (HIGH).

The **objective** of seeking the optimal strategy is to find such dynamics of management of internal factors that would increase the enterprise's "Market share" without increasing or, better yet, lowering the activity of the "Product price" factor.

Such management is shown in *Figure 2a*. It reflects the dynamics of the activity of the "Quality control," "Enterprise's productivity" and "Product competitiveness" factors, which gradually improve over time (the activity of these factors grows). The result of such management is the growth of the enterprise's "Market share," on the one hand, and the drop in the "Product price" on the other (*Figure 2b*).

We can see from *Figure 2a* that to increase the enterprise's "Market share" and reduce the "Product price" for the product being introduced, it is necessary to increase the activity of all three controllable factors, but in different orders and to different degrees. First of all, the "Enterprise productivity" in terms of output needs to be significantly increased. The emphasis needs to be on the outstripping growth of this controllable factor; the growth of its activity has to be at its fastest and best (reaching a level above 0.9) by the end of the simulation period.

The rest of the controllable factors are distributed as follows in terms of their impact on the result. The second most important factor is "Product competitiveness" in the market of similar products. At the very beginning of the simulation, the activity rate of this factor is a little inferior to that of the "Productivity" factor, but it significantly exceeds the rate of the "Quality control" factor. In order to achieve the target (an increase in the "Market share" of the new product), "Quality control" should be focused on only in the third step of the sim-

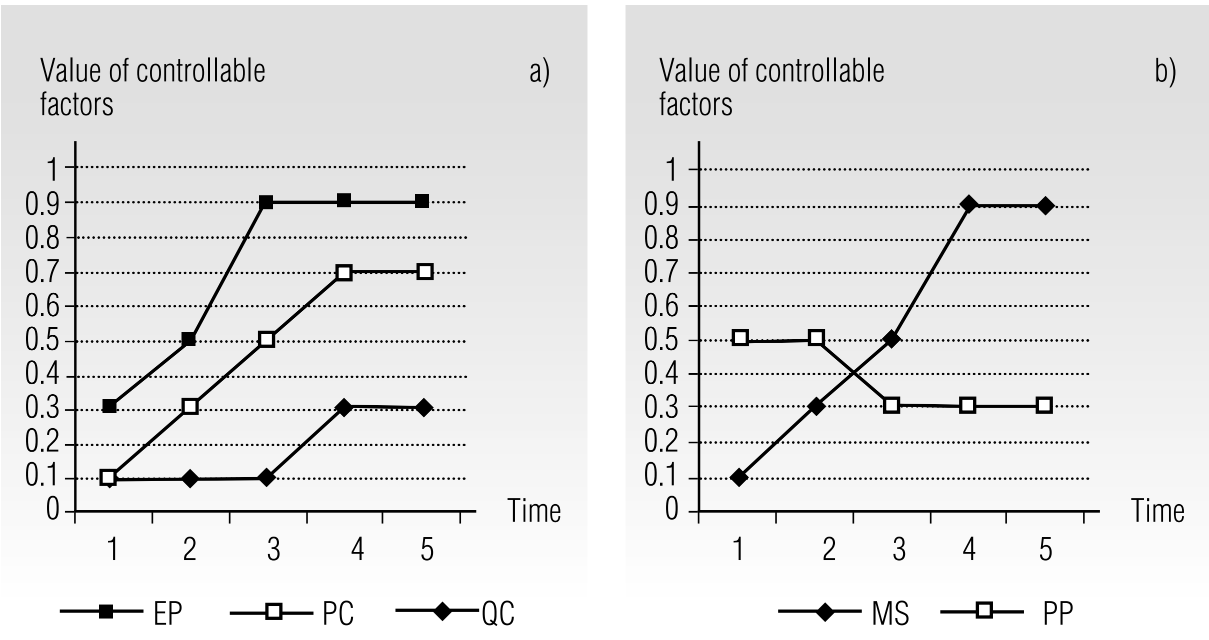

Fig. 2. Management strategy dynamics for the introduction of a new product by an enterprise with a small market share

ulation, when the initial increase in market share will be achieved. After the fourth step, the requirements for the activity of the "Quality control" factor can be lowered again (after this moment, the growth rates of the "Product competitiveness" and "Quality control" factors are equalized).

The results of modeling with the cognitive map in Figure 1 show that its expansion is possible even for an enterprise with small market share. This requires stable economic conditions and a certain sequence of steps to control and regulate the control actions on the internal factors of the "client" level.

3. Applied possibilities of cognitive models

The above example is a demo. In real-life projects, cognitive maps can have a more complex structural and functional organization [8–10]. The issue of reliability of cognitive maps is of great importance in cognitive modeling of strategies. Its solution largely depends on the correct choice of the basis factors and the cause-and-effect relations of the map being built. This issue remains open in the theory of cognitive modeling to date. At the same time, substantial assistance in solving the issue can be provided by:

✦ D. Waterman's excellent guide to expert systems [11] that helps a knowledge engineer avoid numerous "traps" arising in the planning and designing of cognitive models and working with experts. In the development of cognitive models, as with all other knowledge-based technologies, the key role belongs precisely to a knowledge engineer rather than mathematicians, psychologists or programmers [11];

✦ known expert evaluation methods (interviewing, questionnaire survey, Delphi method, "round table" and "brainstorming" methods);

✦ various versions of PEST analysis of the external environment by groups of conditions: P – political and legal, E – economic, S – social, T – technological;

✦ various versions of SWOT analysis (S – strengths, W – weaknesses, O – opportunities, T – threats) widely used to assess an enterprise's strengths and weaknesses in interaction with threats and opportunities of the external environment;

✦ known models of strategic analysis and strategic planning: the Kaplan–Norton strategic map, BCG matrix, ADL/LC, Hofer/Schendlel, Shell/DPM models, etc.;

✦ methods and models of scenario analysis [12] and scenario planning [13];

✦ SMART-technology of goal setting [14];

methods of extracting knowledge in knowledge-based technologies [15];

✦ methods of psychosemantics [16] and non-metric multidimensional scaling [17] that allow one to assess the degree of consistency of opinions of strategy developers (top managers, business consultants, subject experts) at the most debatable stages of strategic analysis (translation of the mission into strategic goals, building a cognitive map, parameterization of a cognitive map, verification of goals for completeness and inconsistency, reduction of the cognitive map in order to eliminate insignificant details, etc.).

The technique of cognitive model building (like all other knowledge-based models) is specific and involves a gradual and multistage design: developing a demonstration prototype, developing a research prototype, then an operational prototype and, finally, creating an industrial prototype suitable for solving real-life problems [11]. We believe it is necessary to emphasize once again that in the paper, we present a demonstration prototype of a cognitive model, which, in our opinion, gives quite a convincing indication of the high potential of the application possibilities of this class of models. The creation of industrial prototypes that take into account the numerous features of a specific enterprise and its external environment is usually labor-consuming and expense-wise can significantly exceed the costs of developing a demonstration prototype.

Conclusion

Cognitive tools offer great opportunities for solving critical problems of modern management. First of all, these are issues related to the generation of alternative strategies and the assessment of their effectiveness in the context of the multifactor dynamics of an enterprise's internal and external environment.

The emerging possibility of purposeful generation of effective strategies significantly broadens the scope of strategic search and creates the prerequisites for shifting to a new paradigm of strategic choice: not choosing the best available alternative (the paradigm of RAND Corporation, USA) but building a better one.

An important (and possibly unique) advantage of cognitive tools is the opportunity that they reveal – that of exploring the delicate structure of management strategies (the necessary sequence of the inclusion of managerial impacts, the necessary degree of activity of these impacts, the study of the dynamic stability of strategies, etc.). None of the known strategic management support tools is capable of that. Another important advantage of cognitive models is that they allow one to study the dynamics of strategies at a qualitative level without using hard-to-access and not always reliable quantitative statistics. This is extremely important in the context of today's rapidly changing business environment and the growing pace of technological innovation.

Cognitive dynamic analysis significantly expands the tool base of strategic management which is based today mainly on the tools of static situational analysis and prescriptive decision-making schemes.

The possibilities of cognitive modeling also open new prospects for the "cognitive school" of management [18]. The latter, say the authors of this book, "is characterized more by its potential than by its contribution," and they use the term "cognitive school" not because it really exists today, but because "its importance can lead to creation of such a school." ■

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