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Cognitive Approach to Control of Socio-Economic Systems Security

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Abstract - *The foundations of technique of cognitive analysis of socio-economic objects (enterprise, city, region, state, etc.) security and working out of secure strategies of their development, that have been worked out by the Institute of Control Sciences of the Russian Academy of Sciences are considered herein. The socio-economic object (SEO) security is considered herein as such SEO state that provides its purposeful development under transformation of external and internal environment. The technique is based on cognitive approach to modeling and includes the following stages: cognitive structuring; construction of cognitive model of SEO; structure and goal analysis of the model; scenario modeling of a situation development; interpretation of results; cognitive monitoring.*

Keywords: Systems modeling and control, policy and decision support systems, cognitive systems engineering.

1 Introduction

Technique of cognitive analysis of socio-economic objects (SEO) security is based on cognitive approach to analysis and modeling of situation development and lies in recognition and forestalling of threatening tendencies inside and outside of a SEO, that (tendencies) can:

- present a danger of crisis situations development, consequences of which can be a reason of severe economic, social, ecological, etc. damage;
- prevent SEO from its purposeful development.

The traditional approach to SEO security control, based on "react and eliminate consequences" strategy, is found to be ineffective under uncertainty and is forced to give way to the new one, based on "forecast and prevent" strategy.

Purposeful and secure SEO development is impossible if the external environment (socio-economic, political, etc,) influence is not taken into account. This is caused by the fact that modern period of society development is characterized by becoming more frequent crisis and extraordinary situations, i.e. events, that are beyond existent experience and that need special measures to be prevented and eliminated. At the same time, threatening tendencies are often becoming apparent long before they develop into crisis.

A socio-economic object security is understood herein as such SEO state that provides its purposeful development under transformation of external and internal environment. Events, facts, and changes in the internal and external environment, that prevent SEO from its purposeful development, are considered herein as threats. Definition of threats depends on goals of SEO development. The secure strategy of development is the strategy providing the SEO security during its purposeful development.

In contrast to technical systems and objects which security parameters and criteria are, as a rule, known and can be easily formalised, socio-economic systems and objects belong to weak-formalizable ones. That is caused by (1) the fact that economic system behaviour is influenced by a number of factors of various nature (economic, social, political, connected with international activity, etc.); (2) absence of sufficient quantitative information on the processes influencing economic systems development. Therefore a peculiar approach, that will allow taking into account all essential diverse factors that determine SEO security, is needed. Besides, techniques used within the framework of such approach, should allow to receive results as soon as possible because of lack of time a decision maker has and growing risk and damage from wrong decision, caused by acceleration of economic, and other processes and their uncertainty [5].

Methodology of cognitive modeling, meant for analysis and decision support in poorly determined situations, has been posed by R. Axelrod [2], and

mathematical foundations of cognitive modeling - by F. Roberts [4].

Cognitive approach provides discovering of strengths and weaknesses of a SEO on the basis of observation of model factors dynamics. The idea of established SWOT-analysis is used when the one defines threats and opportunities to SEO development.

SWOT-analysis is the analysis of strengths and weaknesses of SEO development in their interaction with threats and opportunities of external environment. SWOT-analysis enables to discover relevant problem fields, weak points, dangers and additional opportunities for SEO functioning and development. In general, procedure of SWOT-analysis is reduced to filling of a matrix "window of opportunities" where strengths and weaknesses of SEO are confronted with threats and opportunities, that makes a problem field. The procedure is usually carried out with participation of experts.

Analysis of structural features of SEO development cognitive model – one of the stages of technique of cognitive analysis and modeling – enables to work out the formal procedure of matrix "window of opportunities" filling. Thus, there is no necessity in attracting experts with all accompanying procedures. It is especially important for continuous monitoring of situations around and inside of SEO and when the express analysis is needed to cope with originated problem situation.

2 Cognitive technique of SEO security analysis and modeling

The worked up technique of cognitive analysis and control of SEO security is a cyclic process that includes 5 stages (Figure. 1).

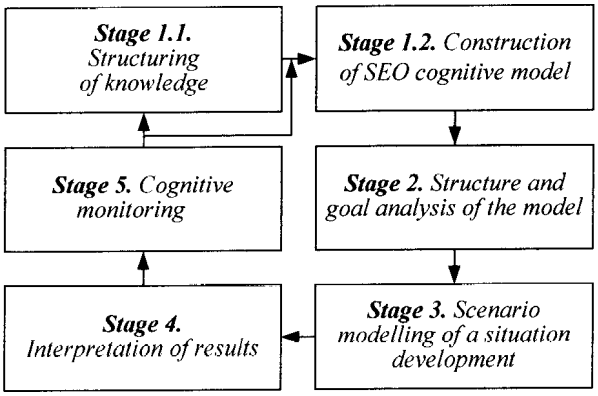

Figure 1. Stages of cognitive analysis and modeling

2.1 Cognitive structuring

At the present stage (1) structuring of knowledge on economic object and (2) creation of cognitive model of SEO security are carried out.

Structuring of knowledge on socio-economic object is carried out by means of PEST-analysis of information - internal analytical sources, releases, mass media sources, expert opinions, etc.

Results of the carried out analysis are: (1) set of factors that essentially influence the SEO security (basic factors); (2) problem areas of situation that describe threats to SEO security and gaps in its maintenance.

Construction of SEO cognitive model. Formally cognitive map represents a square table [3], in which:

- lines and columns correspond with the basic factors of a situation in terms of which the processes in a situation are described in a one-to-one manner;
- the element that is situated on crossing of line "*i*" and column "*j*" reflects the fact of direct influence of the factor "*i*" on the "*j*" one. Sign of this element displays a sign of influence (positive or negative), and the module - strength of such influence in the appropriate scale.

Cognitive map is the initial static representation (reflection) of connections between the factors existing in a situation under research. To solve the problem of SEO security control it is necessary to construct a dynamic simulation model and on its basis to obtain a new knowledge of the structure and dynamics of a situation under research.

Analysis of a graph model of a situation associated with a cognitive map allows to reveal the structural properties of a situation. The basis of the model is a weighed digraph $G = (X, A)$, where X is a set of nodes that biuniquely corresponds to the set of basic factors, A is a set of arcs reflecting the fact of direct influence of factors. Each arc connecting some factor x_i with some factor x_j has the weight a_{ij} which sign depicts the sign of influence of the factor x_i on the factor x_j, and the absolute value of a_{ij} depicts the strength of the influence. Thus, the cognitive map can be examined as a connectivity matrix A_g of the graph $G = (X, A)$.

While the situation evolves each factor is being influenced not only by "neighboring" factors, but also by more "distant" ones and these indirect influences are transferred through chains of the appropriate factors and graph arcs that connect them. Set of influences as direct, and indirect to which each factor in a situation is subject is described with the use of concept of transitive closure

of a cognitive map of the situation, determined as the sum of infinite power series

$$E_n + A + A^2 + \ldots + A^t + \ldots \qquad (1)$$

of matrix A. Each element of this row characterizes passage of routes of length "*t*" in the graph, i.e. realization of direct and indirect interferences through one factor, two factors, etc.

Estimation of the sum of this series can be obtained only if the graph *G* adjacency matrix is stable. Then all elements of this series approach to finite limits at unlimited increase of *t*.

To determine the transitive closure it will suffice to consider N terms in a power series of matrix A, where N - the order of matrix A, i.e. number of basic factors in a cognitive map of a situation. Then the transitive closure of matrix A is estimated by matrix:

$$Q = E_N + A + A^2 + \ldots + A^N \cong \left(E_N - A\right)^{-1} \qquad (2)$$

At the same stage vectors of SEO goals and controls are formed.

2.2 Structure and goal analysis of the model

At this stage the one analyses the goals of SEO development and controls used for their achievement on consistency and determines the most efficient control actions.

Vector of goals *Y* is consistent if [1]

$$r_j r_k = sign(q_{ik}) \text{ for any } y_i, y_k \in Y . \qquad (3)$$

where q_{ik} - *(i, k)*-th element of matrix Q.

If (3) is fulfilled for goal factors y_i, y_k they refer to as consistent, otherwise these factors are inconsistent.

When the consistent vector of goals is formed the desirable integrated change of any of goal factors will not result in undesirable integrated change of other goal factors in a vector of goals.

Vector of control factors is consistent [1] with a vector of goals *Y*, if for each coordinate of a vector of control actions $U=(u_1 \ldots u_p)$ it is possible to determine such sign, that for a resulting sign vector *sign (U)* it will be fair:

$$r_s = sign(q_{st})sign(u_t) \text{ for any } u_t \in U, y_s \in Y \qquad (4)$$

When control factors are consistent with the vector of goals and (4) is fulfilled, any change of control factors according to a vector *sign (U)* will not cause the change of any coordinate of a vector of goals *Y* in undesirable direction. Let *U*(0)* be a vector of control actions the signs of which are selected according to (4), and $|U'(0)|$ - vector *U'*(0) in which all coordinates are replaced with their absolute values.

The essence of realization of control actions consists in such change of control factors that their influence on goal factors will result in favorable changes of goal factors, i.e. to changes of goal factors in desirable direction.

The desirable direction of change of the factor x_i is determined by a parameter (estimated value) r_i, that possesses the value +1 if the increase of value of the factor x_i is desirable, and -1 if reduction of the factor x_i is desirable.

If the one finds difficulty in determination of a desirable direction of the factor x_i change, r_i is considered to be equal to 0. The parameter r_i refers to as the attitude to factor's x_i dynamics (AFD).

In this connection it is important to answer the question "which of the control factors are the most "effective" for reception of a positive effect if compared by their integrated influence on goal factors?".

Formally, the parameter of efficiency $E(u_k)$ of the control factor u_k (i.e. the maximal positive effect from the change of u_k) is determined as absolute value of the sum of coefficients of influence of the given control factor u_k on the goal factors multiplied by AFDs of the goal factors, i.e.

$$E(u_k) = \left| \sum_{i=1}^{m} r_i q_{ki} \right|, \qquad (5)$$

where r_i is the EFC of the goal factor y_i,
q_{ki} - *(k,i)*-th element of matrix *Q*.

Really, the maximal positive effect Δy from realization of control u_k on the factor x_k is estimated as

$$\Delta y = \left(\sum_{i=1}^{m} r_i q_{ki} \right) u_k , \qquad (6)$$

where the sign of action g_k coincides with the sign of the sum

$$\sum_{i=1}^{m} r_i q_{ki}$$

,

and its value is equal to 1.

2.3 Scenario modeling of a situation development

At the present stage modeling of a situation development is carried out. Modeling can be carried out in conditions of SEO self-development (without any actions to modify processes in a situation, when a situation is allowed to run its natural course) and SEO development under control.

Scenario consists of a set of factor tendencies describing a situation at the present moment, desirable goals, a set of activities that are used upon the running of a situation, and system of observable parameters (factors) illustrating behavior of processes.

2.4 Interpretation of results

At the given stage, the most essential threats to secure SEO development are determined and the secure strategies of SEO development are worked out on the basis of the results drawn at the previous stage.

2.5 Cognitive monitoring

Cognitive monitoring includes observation of the current situation around SEO as well as discovering tendencies, threatening to SEO secure development. Monitoring of the current situation enables to discover new key factors influencing SEO development. In this case the model is updated.

Cognitive monitoring of a SEO development security consists in discovering of threatening tendencies of external environment and weaknesses of SEO, which can both become a reason of crisis or prevent the SEO from its purposeful development.

Analysis of structural features of cognitive model of SEO development, the essence of which, when carrying out SWOT-analysis, is reduced to comparison of initial tendencies of factors (a set of model inputs) and integrated influences with desirable changes of factors (a set of model outputs), enables to determine which external (X^{ext})/internal (X^{int}) factors favorably or unfavorably influence X^{int}/X^{ext}.

If the tendency of an internal factor is unfavorable, the one is considered as a weakness, otherwise – as a strength of SEO.

The initial tendencies of X^{ext} do not obviously tell the one which of them are threats, and which – opportunities. Dynamic modeling of a situation (self-development) can only show how the initial tendencies of X^{ext} influence X^{int} as a whole – without specifying the influence of a single factor.

3 Software realization

Computer support of Stages 3-6 of the described technique is provided with the developed modeling dialogue software package "Situation - 2".

DSP “Situation-2” ensures:

1. Construction of cognitive model of a situation :

– selection and substantiation of the basic factors of a situation;

– construction of graph model of a situation.

2. Structural interpretation of problems requiring solution in the situation.

3. Structural analysis of the situation under research.

4. Searching and substantiation of secure strategies:

– choice and substantiation of the desirable goals;

– choice of activities (controls) necessary for reaching of goals;

– analysis of basic possibility of reaching of goals from an initial state of a situation with the use of selected activities;

– analysis of restrictions on a possibility of realization of the selected activities in reality;

– analysis and substantiation of a real possibility of goal reaching;

– development and comparison of secure strategy of SEO development.

5. Substantiation of possible scenarios of the situation development.

6. Machine generation of the reports and systematization of results of a problem modeling.

DSP “Situation” allows to examine two classes of analytical problems:

– structural analysis of a situation;

– scenario exploration of a situation development trends.

Thus, the key result of the carried out research is the new technique of analysis of a socio-economic object security based on cognitive approach to modelling.

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