# DYNAMIC MULTI-CRITERIA DECISION MAKING METHOD FOR SUSTAINABILITY RISK ANALYSIS OF STRUCTURALLY COMPLEX TECHNO-ECONOMIC SYSTEMS

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## Abstract

The paper considers the characteristics of the functioning and sustainability of the structurally complex techno-economic systems (SCTES) in terms of different types of risk. The validity of the application to describe the behavior of this class of systems of semi-empirical mathematical models, which are based on a vector description of the system states, using the criteria approach for assessing the quality of its functioning, is demonstrated.

Under discussion is conceptual model for the interaction of the object and its environment, allowing to estimate the "optimal" allocation ratio between the productive system and its development potential.

The concept of non-formalizable threats for the sustainable functioning of this systems class was introduced. Expert procedure to account non-formalizable threats in case of risk assessment was proposed. For the construction of indicators for assessing the status the methods of quantitative analysis based on the theory and multi-criteria utility was used. Multi-criteria utility as an indicator of sustainability in the form of dimensionless complex hierarchy of indicators was proposed. Computing for through the convolution of the primary indicators.

The hierarchical model proposed to calculate the integral index of multi-criteria preference of one embodiment of the system over the other. Some results of case study are discussed.

**Key words:** structurally complex techno-economic systems, risk analysis, sustainability, multi-criteria method

SCTES are characterized by distribution in space, big variety and interaction of objects types, non-uniform structure of processing chains, unique conditions of influence of risks of the various nature on objects of the subsystem and the system as a whole.

In the idea of situation management of SCTES principles of changeable (adaptive) behavior in terms of possible risks and uncertainties are initially put. Presence of such risks generated by different circumstances is capable to brake or change this or that way of movement, to force the system to live «under another scenario», different from all variety of plans shaped before.

If as sustainability of SCTES functioning to understand the plan performance of its development with admissible variation on volumes and terms of problems performance then situation safety management in this system is reduced to minimization of hazardous losses at extraordinary situations and to carrying out of actions for their prediction. The success of such tactics depends substantially on intuition and talent of management of the company, on its ability to expect the possibility of weakly formalized threats outgrowth into notable risks and losses.

Under weakly formalized threats we understand here the threat for criticality estimation of which the development of original algorithm of the decision depending on a concrete situation is required and for which uncertainty and dynamism of the initial data and knowledge can be characteristic.

However, in the absence in enough of adequately estimated information necessary for decision-making, tactics of adaptive management quite often turns to a continuous chain of the "emergency" scenarios leading to disruption of controllability of all system. Hence, company management should be engaged not only the current work bringing quite notable results which utility is measured in economic factors, but also to care of creation the company condition monitoring system and the world surrounding it, watching dynamics of internal and external threats to its growth and development.

That is optimal control of SCTES aimed at reception of profit on its activity, consists in ability to find balance of redistribution of the available resources (material, human, information) by proprietor of the company between «productive activity» and «maintenance of development potential ».

The elementary model illustrating the abovementioned and allowing to estimate "optimal" proportions of resources distribution between "useful" (production) system and its development potential is the model of interaction of developing object and its environment (**Klykov, 1970; Zhigirev, etc., 1983**).

Let's present the activity of some SCTES, consisting of two subsystems (fig. 1).

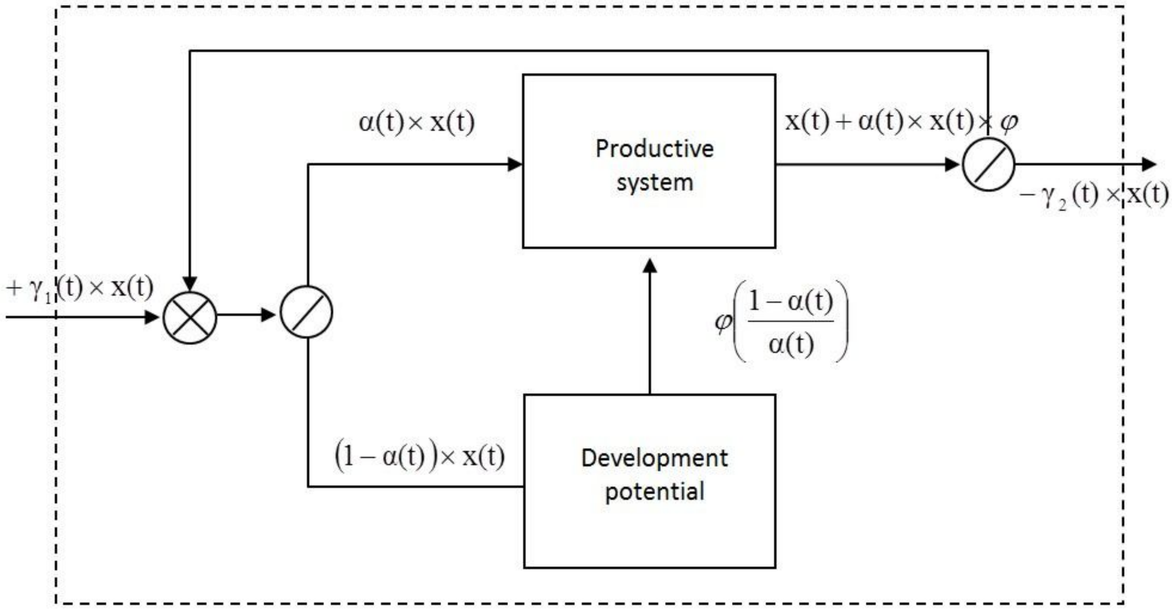


**Figure 1.** Activity of productive system

The first, «productive subsystem», brings profit, proportionally to quantity of received resources $(\alpha(t)\times x(t))$ with some positive resources increase speed coefficient $\varphi\left(\frac{1-\alpha(t)}{\alpha(t)}\right)$, available in the system.

The second subsystem - «development potential» plays the role of the accelerator (retarder) of resources reproduction speed in the system.

Herein $\alpha(t)$ is proportion of resources distribution between productive subsystem and its development potential, $\gamma_1(t), \gamma_2(t)$ - coefficient of resources exchange intensity between investigated system and some external in relation to it system in the process of coexistence.

Actually the difference $\gamma(t) = (\gamma_1(t) - \gamma_2(t))$ is the share of resources deduced from the cycle of reproduction in the form of losses of one kind or another, for example, of final consumption, taxes, etc.

In the elementary representation "potential" influence is the value of function $\varphi\left(\frac{1-\alpha(t)}{\alpha(t)}\right)$ and coefficient $\gamma(t)$ for large-scale systems we consider independent of times in an explicit form as constants. In this case system development is described by the homogeneous linear equation on a variable $x(t)$ at parameters $\alpha$ and $\gamma$

$$\frac{dx(t)}{dt} = \alpha(t) \times x(t) \times \varphi\left(\frac{1-\alpha(t)}{\alpha(t)}\right) + \gamma \times x(t) \tag{1}$$

The optimum proportion $\alpha^*(t)$ between productive system and its development potential is defined from the condition

$$\alpha^* \times \varphi\left(\frac{1-\alpha^*}{\alpha^*}\right) \to \max \tag{2}$$

At the natural assumption that $\varphi(\xi)$ is monotone function with saturation (fig. 2) there is a simple way of its optimum definition, as $\alpha = \left(\frac{1}{1+\xi}\right)$.

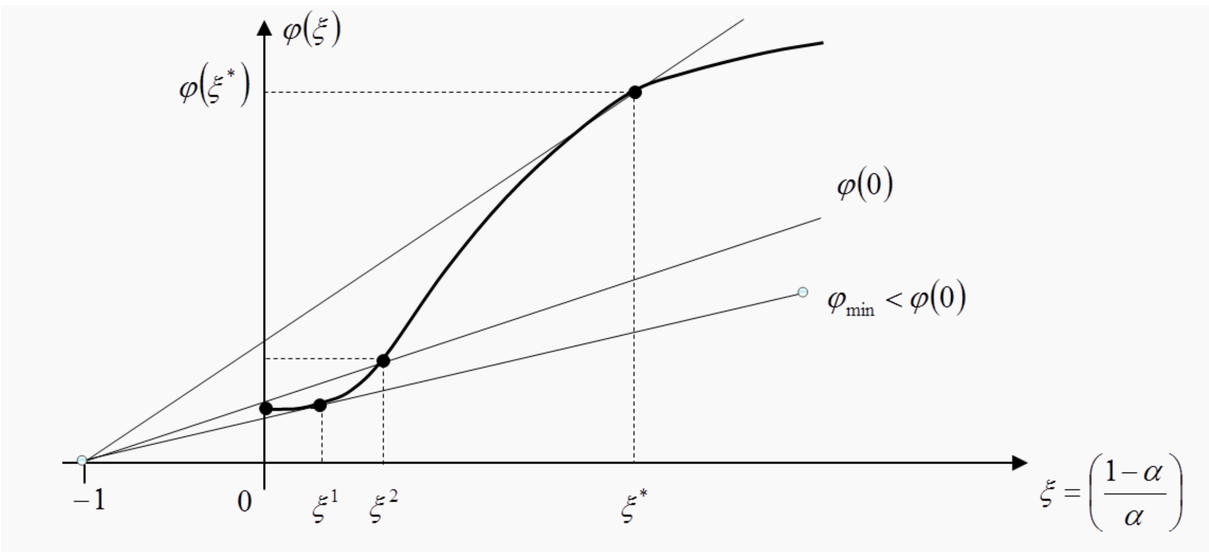


**Figure 2.**

According to fig. 2 it is clear that this optimum is reached in some point $\xi^*$, having quite certain sense. So, if resources for development potential are allocated «excessively much» $(\xi \succ \xi^*)$, then means $(\xi - \xi^*)$ are incorrectly withdrawn from the current reproduction and there is a situation when efforts to studying and counteraction to numerous risks which the developing system can never come across are spent.

The point $(\xi = 0)$ corresponds to the situation when all resources are spent exclusively for growth of productive system. The potential of similar system is low because of constant losses which it is possible to avoid if there is a potential for prediction of arising risks and struggle against them.

The segment $\xi = \left(0, \xi^1\right)$ shows that if the means allocated for studying and counteraction to threats and risks are small, then return from similar researches and done actions less than the resources allocated for them. Information gathering, research of internal and external threats on a low level doesn't allow to receive an adequate estimation for improvement of decision-making quality in most cases anyhow developing circumstances.

On the segment $\xi = \left(\xi^1, \xi^*\right)$ the contribution to development potential starts to give positive return, however only in the point $\xi^2$ the level of "self-support" of expenses for development of "potential" of system will be reached $\left(\varphi\left(\xi^2\right) = \varphi(0)\right)$.

Therefore it is expedient to consider this point as the point of "critical" position.

Decrease of potential $(\varphi(\xi))$ to the level $\left(\varphi\left(\xi^2\right)\right)$ threatens that "in accordance with the circumstances" economically expediently there will be «strategy of survival» – strategy of full refusal of expenses for the decision of problems of prediction and anticipation of threats and risks and reproduction maintenance only at the expense of escalating inefficient capacities in productive subsystem $\xi \to 0$.

In spite of the fact that the conceptual model stated above is schematical, it, nevertheless, provides guidance that threats and risks as a matter of fact are "antipotentials" of development, that is they are retarders of speed of all system reproduction.

Since SCTES, as a rule, are non-uniform, they are subject to risks various by the nature and on influence levels. The received expert estimations of optimum proportions, certainly, need updating if to consider balanced development of the system consisting from many productively and territorially connected subsystems.

The logic of optimum proportional development in this case also remains. Received estimations should be considered only as "reference points" for the further researches, otherwise struggle for escalating of development potential will be carried out only in those territories and only in those productive-technological chains for which it by theoretical estimations is "economically expedient" that will lead to destruction of integrity of the system (connectivity loss), withdrawal from unified state and branch standards.

Let's suppose that the exit of investigated system runway from admissible corridor (a component of the vector of functioning efficiency indicators) can be caused to four reasons:

a) owing to increase of importance of the problems put before the system to such level that default of these problems at occurrence of extraordinary situation (and furthermore in a normal mode of functioning) appears critical for system existence, up to necessity of its re-structuring as a whole;

b) owing to system simplification or destruction at which locally arising extraordinary situations are really capable to outgrow in events with large-scale losses under scenarios of cascade type;

c) owing to dramatic or long deterioration of operating conditions of objects and subsystems in one or several territorial formations formed, including, as a result of non-formalizable threats increase;

d) owing to decrease in level of industrial and fire safety and (or) physical protection for technological blocks and objects of various type.

It is offered for an estimation of extraordinary situation threat level in SCTES to use the following hierarchical multi-criteria model (**Russman, 1991**).

Integrated risk of extraordinary situation $R(r_1, \ldots r_i, \ldots, r_n)$ represents function of risks of private extraordinary situations occurrence $r_i \ (i = 1, \ldots, n)$. The kind of dependence $R$ on the arguments gets out proceeding from conditions:

$$0 \le R(r_1, \ldots, r_i, \ldots, r_n) \le 1 ; \qquad (3)$$

$$R(0, \ldots, 0, \ldots, 0) = 0 ; \qquad (4)$$

$$R(0,\ldots,r_i,\ldots,0) = r_i; \tag{5}$$

$0 \le R(r_1,\ldots,1,\ldots,r_n) = 1$ for $\forall\ r_i = 1$ irrespective of values of other arguments. (6)

Continuous function $R(r_1,\ldots r_i,\ldots,r_n)$, meeting (3)-(6), has the following general view

$$R(r_1,\ldots r_i,\ldots,r_n) = 1 - \left\{\prod_{i=1}^{n}(1-r_i)\right\} \times g(r_1,\ldots r_i,\ldots,r_n), \tag{7}$$

where $g(0,\ldots,r_i,\ldots,0) = 1$.

If in special case $g(r_1,\ldots r_i,\ldots,r_n) \equiv 1$, then formula (7) is of the form

$$R(r_1,\ldots r_i,\ldots,r_n) = 1 - \left\{\prod_{i=1}^{n}(1-r_i)\right\} \tag{8}$$

states the underestimated estimation of integrated risk from calculation that the stream of extraordinary situations represents a mix of ordinary events taken from homogeneous, but differing with values $r_i$ $(i = 1,\ldots,n)$ samples.

But for real systems risks, as a rule, are dependent.

Then we have

$$g(r_1,\ldots r_i,\ldots,r_n) = 1 - \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} C_{ij} \times [r_i]^{\alpha_{ij}} \times [r_j]^{\beta_{ij}} \tag{9}$$

$$\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} C_{ij} \le 1 \quad C_{ij} \ge 0$$
$$\alpha_{ij} > 0 \tag{10}$$
$$\beta_{ij} > 0$$

where $C_{ij}$ - coefficients of risks connection of $i$ and $j$ extraordinary situation; $\alpha_{ij}$ and $\beta_{ij}$ - positive coefficients of elasticity of replacement of corresponding risks, allow to consider the facts of risks replacement, caused mainly by that simultaneously effective actions for decrease in all risks can't be done owing to limitation of time and resources.

The current risks values $r_i$ $(i = 1,\ldots,n)$, entering integral risks factor $R$ are values changed in time with various speeds (for example depending on the seasonal factor priorities of solved technological problems essentially change).

Thereof classical calculation of risks equation leads to problems of combinatory complexity on the initial data having objectively casual, uncertain, often qualitative (semiquantitative) nature.

The decision of problems of risks analysis becomes complicated also because non-formalizable threats can play considerable role.

For the account of these factors it is offered to form values $r_i$ as product of four components:

$$r_i = r_i^{(a)} r_i^{(b)} r_i^{(c)} r_i^{(d)}. \tag{11}$$

The component $r_i^{(a)}$ in (11) is estimated through categorizing of problems the performance of which is cancelled or delayed owing to the arisen extraordinary situation (for example, in gas supply systems categorizing can be defined through percentage distribution of categories of power users, affected in case of extraordinary situation because of the termination of gas supply).

The component $r_i^{(b)}$ is estimated through maximum permissible losses (MPL) in extraordinary situations at existing technological levels and materials (subjectively established) calculations of such losses.

Before achievement the level of MPL $r_i^{(b)}$ can be considered as linear function

$$r_i^{(b)} = \frac{\mathrm{L}_i}{\mathrm{MPL}}, \tag{12}$$

where $\mathrm{L}_i$ - current level of losses.

At exceeding of the level of MPL $r_i^{(b)}$ fixed with value 1.

The multiplier $r_i^{(c)}$ is estimated as dimensionless value, is calculated under empirically picked up statistical data about characteristics of objects in a binding to their territorial placing and has the meaning of indicator of absolute vulnerability of object on which the scenario of $i$ extraordinary situation is initiated.

In general $r_i^{(c)}$ can be considered as the indicator of environment aggression in which the object functions.

For each territory owing to geographical factors, features of productive structure, sociocultural, ethnic and other differences the construction of unique models of calculation significantly found on personal assessment of the experts familiar with this specificity is required.

And a last, valuation of $r_i^{(d)}$ is in terms of ranging of objects types. It reflects quality of relative "susceptibility" of objects of the set type on a wide range of external changes of the factors defining $r_i^{(c)}$. Values $r_i^{(d)}$ are used so that to result estimations of risks of extraordinary situations initiated by events on objects of various types to a uniform scale.

The offered scheme of calculation of integrated index $R$ is mainly intended for the preliminary analysis of variants of system development on the basis of hierarchy of the indicators characterizing all aspects of extraordinary situations including both estimations of consequences $r_i^{(a)}$, $r_i^{(b)}$, and estimations of causes $r_i^{(c)}$, $r_i^{(d)}$.

Lines of levels of $R$ values allow to build borders of reaction zones to changes of all spectrum of risks: $R \geq R_{\kappa p}$ (a "red" zone demanding change of the existing mode of functioning or additional means for decrease of risks $r_i^{(c)}$ and $r_i^{(d)}$), $R_{\kappa p} \geq R \geq R_{op}$ (an «orange» zone demanding balancing of contract activity, carrying out of diagnostic and other actions), $R \leq R_{op}$ (a "green" zone in which pertinently to speak about growth and the further development of the system, introduction of new capacities and new risks connected with their occurrence).

It is obvious that between developing object what is any of SCTES and its development potential, one of the components of which is the subsystem of safety (risk) management there should be a balance. High-yielding system with the underestimated risk is doomed to inefficient functioning owing to losses and on the contrary, the excessive safety concern leads to withdrawal of resources from a cycle of reproduction.

Thus, for SCTES, having diversified multiphasic production and difficult space-territorial topology of estimations having only economic character are unacceptable. Expediently complex development of development potential control system which can be realized, for example, within the limits of audit formly occurred crisis and precritical situations, estimation and generalization of experience, development of system of indicators of early detection of threats to steady functioning of objects (groups of objects).

Let's notice that during development of such indicators system for realization of situational approach to management of the company, it is necessary to accept a number of "reconciliatory agreements».

The first main agreement consists that preservation of integrity of system and knowledge (information) about it is more significant, rather than economic success of separately taken productive element or productive-territorial formation.

The second agreement: threats and risks are considered as factors, braking development potential and, accordingly, use of the device of an estimation of the analysis and risks management without taking charge for risks corresponding to their competence by regulatory bodies is impossible. Concealment of risks or their revaluation'll become a subject of economic auction, inappropriate in the conditions of approaching threats.

The third agreement: pure «one-criteria» approach when to every disovered risk (social, economic, foreign policy) "cost" estimation of consequences of its realizations and (or) prevention of scenarios of their expansion is offered, isn't universal.

Activity of any person separately, groups of people, labor collective of the company as a whole many-sided and various, the use of multi-criteria approach with elements of "indistinct" logic, with use (as far as data permits) detection device of the latent laws in conjunction with and mutual strengthening of numerous factors therefore is the most pertinent.

The methodological approach taken as a principle offered method has advantage in comparison with the cost approaches, expressed that multi-criteria utility "absorbs" in itself in "share" participation all factors, but not just having cost expression ones (that, however, doesn't allow to remove all uncertainties).

Multi-criteria utility is formed on the indicators having in the basis different dimensions, units and scales of measurements which are easily arranged in the presence of computing resources to specific features of investigated objects and risks generated by numerous factors at different circumstances of place and time.

Classical schemes of multi-criteria analysis, based on linear and multiplicative convolutions are successfully enough used in design and predesign analysis, at the decision of some problems of situational management in marketing, at risks estimation of continuation or termination of research and developmental works but as SCTES is dynamic system, it is offered to use more developed model of dynamic multi-criteria analysis which will allow to include the situations generated so-called non-formalizable threats and risks-factors into consideration.

## References

Klykov, Yu. I. (1974) Big systems situational management. «Energiya», Moscow – 130 p.

Zhigirev, N.N. (1983), Vorobiev, E.I., Kuzmin, I.I., Reznichenko, V.Yu. Model of interaction of developing object with environment. // Preprint Institute of Atomic Energy 3799/16. - 69 p.

Russman, I.B. (1991), Kaplinskiy, A.I., Umyvakin, V.M. Modeling and algorithmization non-formalizable problems of the best variants of system choice. Voronezh: VSU - 168 p.