Methods for Modeling Sociopolitical Processes to Address Issues of Integrated Security in Caspian Region

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Abstract. The article dwells on the issue of ensuring integrated security in the Caspian region. It was noted that this region, due to its geographical location, is strategically important for the implementation of Russia’s internal and foreign policy, so any changes in it should be carefully thought over and analyzed for possible consequences. To address the issues of ensuring integrated security, the authors considered the main methods for modeling social and political processes that can be applied to simulate the consequences of specific managerial decisions in the Caspian region.

Keywords: Caspian Sea; integrated security; mathematical modeling.

1. Introduction
The Caspian region has always been an important issue in the foreign and internal policy for Russia, and in light of the consequences of the economic crisis, the emphasis in the policy and economy was shifted from Europe to the regions, as a result of which the Caspian region began to attract the attention of not only Eurasian researchers but also the world political elite. Its peculiarity lies in the fact that the Caspian region, being the cradle of the Eurasian civilization, is primordially a kind of a balanced cocktail, characterized by mixing nationalities, religions and cultures, and any interference in this balance can lead to serious consequences both at the intercultural and economic levels. On this basis, any possible changes in this area cannot but affect the national interests of Russia, just as they cannot isolate it from participation in them. Russia's close attention to this geopolitical direction is also caused by the fact that it is a strategically important region in terms of its location, rich biological and hydrocarbon reserves, energy, and economic potential, as well as other parameters. Therefore, ensuring comprehensive security in the Caspian region is an urgent task of state importance.

In this regard, it is necessary to take into account all aspects, factors, interests and goals of actors of sociopolitical processes, and special attention should be paid to interethnic conflicts when making decisions, since the Caspian region is primordially multi-religious and multi-ethnic. In addition, modern society is entering the post-industrial informational period of its formation [4]. Along with expanding creative opportunities, it also leads to increasing threats to national security, associated with violation of the established modes of using information and communication systems, infringement of the constitutional rights of citizens, the spread of malicious programs, as well as the use of modern information technologies for hostile, terrorist and other criminal action.

All these parameters require in-depth system analysis. And the impossibility to test hypotheses and assumptions experimentally limits a decision-maker in making decisions about social or political
processes. This leads to the need for modeling real conditions. Subsequent models, reflecting complex sociopolitical objects, are so complex and multifaceted that it is hard to imagine their effective use beyond mathematical descriptions and the use of computer technology.

2. Methods of modeling

Modeling is a research method based on construction and examination of models of the final objects of research. Studying a model gives a fairly reliable idea of the modeled phenomenon or object to the extent that the model adequately reproduces this phenomenon. Of course, modeling in the social sphere, including the political one, differs significantly from modeling physical, technical and similar objects. However, all social and political processes have both qualitative and quantitative characteristics. This makes it possible to build models of all types to study political objects, including mathematical and computer models.

In practice, the modeling process appears as a complex sequence of interrelated stages (Figure 1). The first of them is a clear statement of the problem at hand. Then the researcher must determine the object of modeling and the object or angle in which he/she wants to consider this object. Then comes the turn of collecting information, a primary study required to form a conceptual model. Next, a conceptual model is formed. If mathematical formalization is necessary, a respective task is selected and a mathematical (or computer) model is adapted to it (or a new one is created), a study is carried out to collect empirical information, mathematical (or computer) data processing is carried out, resulting in an information model that replaces the object under study. An experiment is carried out on this model - mathematical or logical, which is followed by the final stage of modeling – interpretation of the result.

As a subject area of scientific knowledge, the modeling of social and political processes started to form quite recently. Papers on the modeling of social and political processes by Russian and U.S. mathematicians began to appear in the mid-70s of the 20th century.

There is a class of modeling methods that can be considered for addressing the issues of ensuring integrated security in the Caspian region.

V.A. Shvedovsky [5] developed probabilistic mathematical models using the theory of nonlinear dynamical systems. On the basis of statistical information of sociological research data, the author created mathematical models for changing components of the socio-psychological potential of specific ethnopolitical centers. This method can be used to identify regional tensions in the Caspian states in order to make a timely decision to localize hotbeds of unrest and prevent revolutionary sentiments.

A relatively similar problem can be solved through analysis of hierarchies. This approach acts as a general methodology aimed at solving a wide range of problems in the field of making and evaluating the effectiveness of managerial decisions. In other words, the method of analyzing hierarchies allows to evaluate, structure and synthesize various factors, which allows to choose the optimal alternative when...
several criteria are important. Besides, this approach is actively used by scientists to analyze interethnic and interreligious contradictions. Assessment can be carried out both electronically and orally. Papers by T. Saaty and K. Kearns give specific examples of the application of the hierarchy analysis method. This assessment is relevant for the Caspian region, which is a multicultural area [1].

A.A. Samarsky and A.P. Mikhaylov dedicated a number of papers to mathematical modeling using analogies with technical systems, which made it possible to model power systems and build models of corrupt structures and models of a globalizing society [7]. This approach can be used to analyze political alliances and assess the degree of globalization of the Caspian states’ population.

The use of the agent-based method to model processes in social and political systems has become popular since the second half of the 20th century. First of all, this is due to the fact that the methods of computer modeling have found their successful application in the Humanities and natural sciences. Since the 1990s of the last century, the agent-based method has been presented as a powerful tool to model social systems. Besides, the ability to carry out computation on supercomputers makes it possible not only to enable the creation of models of interaction between several people or small communities, but also to imitate the behavior of global social systems and processes within them. This provides a technical opportunity in an artificial environment to simulate processes in different regions, states and throughout the world in general.

The first mentions of the agent-based model of political processes in the aspect of analyzing international interaction and changes in sociocultural norms appeared in papers by T. Schelling and R. Axelrod [8,10]. The contribution of Schelling and Axelrod’s research to the scientific area of modeling social and political processes is that the described models and obtained results showed that agent-based modeling has broad prospects for use, so it began to be used to analyze the processes of social, cultural and political norms, views and values at the international level.

It is also worth noting that agent technologies allow to reproduce complex interactions of “political subjects” almost with realistic accuracy in a virtual environment that imitates the structure of sociopolitical systems and the conditions for their functioning, as well as to test multivariate hypothetical scenarios in the framework of political analysis.

Therefore, analysis of the available approaches to modeling social and political processes showed that each of the modeling methods considered above can cover only one of the aspects of the integrated security of the Caspian region (Figure 2).

![Figure 2. The methods and their applications to problems in the Caspian region](image)

In order to combine the results of each simulation, it is advisable to use a cognitive approach. Cognitive modeling of political processes can combine each of the stages and, at the same time, reflect the specifics of the cultural and ethnic diversity of the Caspian region to the fullest extent possible.

3. Cognitive modeling
Cognitive modeling is actively used to solve problems in the management of various systems. Its use is mainly aimed at creating formal models and methods that provide an intellectual process of solving problems by taking into account human cognitive capabilities (such as perception, cognition, understanding, representation, etc.) when solving control problems. At the same time, tasks that can be attributed to the class of modeling and control problems, where the use of a fuzzy cognitive model for their solution seems to be effective and appropriate, have the following characteristics:

- have some degree of uncertainty of an objective or subjective nature;
- can be assessed both in quantitative and qualitative measures;
- do not have an analytical description of most of the interconnections between parameters.

A cognitive map is a sign or weighted graph over many factors, i.e. directed graph, the vertices of which are associated with factors. In the case of a signed graph, the edges are matched with signs (+ or -), and in the case of a weighted graph – weights in one or another scale. The weights are searched either by means of statistical processing of information or by expert means.

Changes in factors are carried out step by step until the system’s response is determined, after which, using a multicriteria choice, many favorable scenarios are determined and ranked [57].

Different interpretations of vertices, edges and weights on edges, as well as different functions that determine the influence of the connections on factors, lead to different modifications of cognitive maps and means of their study. At the same time, interpretations may differ both in terms of content and mathematics. Due to the presence of many modifications of cognitive maps, we can talk about different types of models, based on these maps.

There are five types of cognitive maps according to the type of relations used:

- evaluating the focus of attention, associations and the importance of concepts (concepts);
- showing the dimension of categories and cognitive taxonomies;
- representing influence, causality and system dynamics (causal cognitive maps);
- reflecting the structure of arguments and conclusions;
- illustrating frames and codes of perception [2].

The control problem in cognitive maps is stated as follows. The situation factors include control factors (factors exposed to direct influence of the decision maker) and target factors, the change or stabilization of which is the goal of management. A specific control decision (strategy) is a choice of a set of control factors.

In a number of interpretations of the sign graph, the possibilities for comparing and ranking solutions are very limited. They can be compared only by the set of target factors on which they have the desired (positive or negative) influence.

The influence analysis method proposed in T. Sawaragi’s paper solves this problem, since it is based on the following assumptions [9]:

1. The strength of the influence of one factor on another along a given path depends on the length of this path (that is, on the number of edges in it).
2. The more parallel influences (along different paths) exist between factors, the stronger the influence between them.

Let $P_{ij}^m$ and $N_{ij}^m$ be the number of positive and negative paths of length $m$ going from the factor $x_i$ to the factor $x_j$, respectively. Then the total positive and negative influences of the factor $x_i$ on the factor $x_j$ are determined as follows:

- positive influence

$$ \bar{P}_{ij} = \sum_{m=1}^{\infty} f(m) P_{ij}^m, $$

- negative influence

$$ \bar{N}_{ij} = \sum_{m=1}^{\infty} f(m) N_{ij}^m, $$
where \( f(m) \) is a monotone non-decreasing function of the path length \( m \) which determines the degree of weakening of the influence on the path from \( x_i \) to \( x_j \).

A monotonically non-decreasing and differentiable function is usually chosen as \( f(m) \)

\[
f(m) = \alpha m,
\]

where \( \alpha \in [0; 1] \) is the coefficient that determines the degree of attenuation [10].

With a decrease in \( \alpha \), the influence of long paths on the final result decreases, therefore, by changing \( \alpha \), one can analyze the influence of paths of different lengths.

To compare various strategies, various variants of the evaluation function \( V(s_i, c_i) \), are considered, where \( s_i \) is the total influence of factor \( i \) on factor \( j \) and \( s_i \) is the consonance of the effect of factor \( i \) on factor \( j \), which are determined from the following relations:

\[
s_{ij} = \bar{p}_{ij} + \bar{n}_{ij};
\]

\[
c_{ij} = (\bar{p}_{ij} - \bar{n}_{ij}) / (\bar{p}_{ij} + \bar{n}_{ij}).
\]

The consonance \( c_{ij} \) is a measure of the difference between positive and negative influences. The larger it is, the more definite the nature of the influence. In particular, the function \( V(s_i, c_i) \) must meet the following requirements.

Let strategy \( i \) be characterized by a pair \( (s_i, c_i) \), and strategy \( i' \) - by a pair \( (s_{i'}, c_{i'}) \). Then, if \( V(s_i, c_i) > V(s_{i'}, c_{i'}) \), \( i \) is preferable to \( i' \).

If \( c_i = 0 \), \( V(s_i, c_i) = 0 \) for any \( s_i \).

If \( c_i > 0 \), \( V(s_i, c_i) \) increases monotonically in both variables; if \( c_i < 0 \), \( V(s_i, c_i) \) decreases monotonically in both variables.

Under some reasonable assumptions, it is advisable to choose the evaluation function in the form \( V(s, c) = VS(s) \cdot VC(c) \).

More detailed characteristics of the interaction of factors can be identified using fuzzy cognitive maps.

The most common approach to calculating fuzzy influences is as follows.

Let there be \( m \) paths between \( f_i \) and \( f_j \), and \( I_r(f_i, f_j) \) denotes the influence of \( f_i \) on \( f_j \) along the \( r \)-th path, and \( T(f_i, f_j) \) denotes the total influence of \( f_i \) on \( f_j \) along all \( m \)-th paths. Then

\[
I_r(f_i, f_j) = \min_{p} w_{p,p+1},
\]

\[
T(f_i, f_j) = \max_{1 \leq r \leq m} I_r(f_i, f_j),
\]

where \( w_{p,p+1} \) is the weight of the directed edge from \( f_p \) to \( f_{p+1} \) on the \( r \)-th path.

Thus, the operation \( I_r(f_i, f_j) \) selects the weakest link in the \( r \)-th path, and the operation \( T(f_i, f_j) \) selects the strongest link \( I_r(f_i, f_j) \).

In problems of dynamic analysis, fuzzy values are attributed not only to connections, but also to factors. In this case, in contrast to the weights of the links, which are considered constant during the analysis, the value assigned to the factor \( v_i \) is the value of some function \( y_i(t) \), which depends on the weights of the incoming edges and the values of the factors input to \( v_i \), and changes with time.

The vector \( y(t) = (y_1(t), y_2(t), ..., y_d(t)) \) of the values of all factors of the situation at the moment \( t \) forms the state of the situation at the moment \( t \) \( \lambda(t) \). The set of edge weights \( w_y \) is given by the adjacency matrix of the graph \( W = \{ w_{ij} \} \). The presence of a value for a factor allows not only to assess the strength of the influence on the factor, but also to express the result of total influences in the form of a specific value.

The concept of the state of the situation allows us to talk about the development of a situation in time under the influence of various external influences, expressed in changes in the values of factors, that is, to set a forecast problem (direct problem), as well as to explore the possibilities of managing the situation, that is, to look for influences leading to the desired (target) state (inverse problem).
Let us consider a simpler case that is quite often encountered in many applied problems, when these functions, firstly, are the same for all factors, and secondly, they depend not on the values of the input factors but on their increments (i.e., the increment value has the same effect in any state) [53].

Let us assume that the range of values of each factor \( v_i \) is a linearly ordered set (scale) of linguistic values:

\[
Z_i = \{z_{i1}, z_{i2}, \ldots, z_{iq(i)}\},
\]

where \( z_{il} \) and \( z_{iq(i)} \) are the minimum and maximum elements of the set, respectively, and \( k < l \) implies \( z_{ik} < z_{il} \).

The powers of the scales \( q(i) \) are different for different factors. The increment of the factor value is characterized by the sign of the increment and its magnitude. For the current value \( y(i) = z_{im} \), passing to the elements \( Z_i: \{z_{im+1}, z_{im+2}, \ldots, z_{iq(i)}\} \) gives a positive increment \( \tilde{P}^+ \); negative increment \( \tilde{P}^- \) is obtained by passing to \( \{z_{im-1}, z_{im-2}, \ldots, z_{i1}\} \).

In the general case, when passing from \( z_{im} \) to \( z_{il} \), the factor gains an increment \( \tilde{P}^i q(\text{sign}(i-m)) \). Obviously, for \( m < l \), the increment will be positive, and for \( m > l \) it will be negative.

For computational convenience, when analyzing situations, we define the mapping \( E: Z_i \rightarrow [0, 1] \) of the discrete linguistic scale \( Z_i = \{z_{il}, z_{i2}, \ldots, z_{iv}\} \) onto the segment \([0, 1]\) as follows. We split the segment \([0, 1]\) into \( r \) equal segments, the boundaries of which are denoted in the ascending order \( b_0, b_1, \ldots, b_{r-1}, b_r = 1 \). Let us put \( z_{gd} = (b_{k+1} - b_k) / 2 \) \( (z_{gd} \) is mapped to the center of the \( k \)-th line segment). This mapping allows to make the algorithms of the fuzzy cognitive model numerical. The inverse mapping \( E^{-1}: [0, 1] \rightarrow Z_i \) is a homomorphism: all points lying in the interval \( (b_{k-1}, b_k) \) are mapped to one point \( z_{gd} \).

Using direct mapping, the state of the situation is represented in a numerical form, and further calculations are performed with a numerical representation of the state of the situation \( \lambda(i) \). Reverse mapping is used only for qualitative interpretations of analysis results.

Thus, cognitive maps allow to combine various modeling methods, which makes it possible to create an effective tool for studying complex systemic processes occurring in sociopolitical institutions through the modeling of interrelated and mutually influencing relations between many social and political actors, which allows to track evolution and dynamics of sociopolitical and economic relations in the Caspian region.

4. Conclusion

- The Caspian region is characterized by mixing nationalities, religions and cultures, and any interference with this balance can lead to serious consequences both at the intercultural and global economic and political levels.
- The world community is interested in ensuring comprehensive security, while modern realities require the adoption of managerial decisions that can upset the balance of a particular geopolitical region. In this regard, modeling is the optimal method for predicting the consequences of certain managerial decisions in relation to the Caspian region.
- The use of various modeling methods makes it possible to create an effective tool for studying complex systemic processes occurring in sociopolitical institutions through the modeling of interrelated and mutually influencing relations between many social and political actors, which allows to track the evolution and dynamics of sociopolitical and economic relations in the Caspian region.
- The use of fuzzy cognitive modeling allows to reflect the specifics of decision-making in the Caspian region to the fullest extent possible.

References

[1] Saaty T. L., Kearns K. 1991 Analytical Planning: The Organization of Systems (Pergamon Press, Oxford, Translated to Russian. Paperback edition, RWS Publications, Pittsburgh).
[2] Azhmukhamedov I. M., Protalinskiy O. M. 2013 Methodology for modeling poor formalized weakly structured sociotechnical systems (Astrakhan: Astrakhan State Technical University
[3] Kuznetsov O.P. 2006 *Cognitive modeling of poorly structured situations* (Moscow Polytechnical Museum).

[4] Brumshtein Yu. M., Markelov K. A., Martynov I. A. 2020 *Images of political leaders of leading foreign countries in Russian citizens’ consciousness: general analysis of management questions* (Astrakhan: Caspian region: politics, economic, culture №3) pp. 147-156.

[5] Shvedovsky V. A. 2000 *Dynamic model of electoral behavior* (Mathematical modeling №8) pp. 46–56.

[6] Shabrov O. Ph. 1996 *Systems approach and computer modeling in political science research* (Social sciences and modernity №2) pp. 100-110.

[7] Samarsky A. A., Mikhailov A. P. 1997 *Mathematical Modeling: Ideas, Methods and Examples* (Moscow)

[8] Axelrod R. 1976 *The Structure of Decision: Cognitive Maps of Political Elites* (Princeton University Press)

[9] Sawaragi T., Iwai S., Katai O. 1986 *An integration of qualitative causal knowledge for user-oriented decision support* (Control Theory and Advanced Technology v.2) pp. 451-482.

[10] Shelling T. 2016 *Micromotives and Macrobehavior* (Moscow Institute Gaydara Press).