UDC 004.8:519.8
DOI: 10.20535/SRIT.2308-8893.2021.3.06

COGNITIVE MODELING OF INFORMATIZATION INFLUENCE ON SOCIO-ECONOMIC INDICATORS OF THE REGION

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Abstract. The article discusses topical issues of the influence of informatization on the development of the country's regions in the conditions of the modern unstable world. The nature of the development of a region can be reflected and understood on the basis of qualitative and quantitative information about its socio-economic indicators, about their relationship and trends in their changes under the influence of internal and external factors. At the same time, information can most often be incomplete, difficult to access, untimely, contradictory, etc. Therefore, in this paper, it is proposed to use a cognitive approach and cognitive modeling of complex systems to overcome the problems of information deficiency by imitating cognitive modeling of the structure and behavior of a complex regional system. The simulation was carried out using the author's CMCS (Cognitive Modeling Complex System) software system. The results of multi-stage cognitive modeling, consisting in the development of cognitive maps "Influence of ICT on the state of the region" and "Digitalization of the republic" (according to the socio-economic state of the Republic of Dagestan), analysis of structural properties and modeling scenarios for the development of situations on the model are presented. Scenarios make it possible to foresee the ways of possible development of the system under the influence of various factors, including the factor of informatization.

Keywords: complex systems, research, cognitive simulation, region, information and communication technologies.

INTRODUCTION

Research question. In the cognitive studies of various complex systems (social, economic, ecological, cyberphysical, etc.) conducted since the beginning of 2000, the features and possibilities of a cognitive approach to their study were studied, and a methodology for cognitive modeling of complex systems was developed. The methodology combines both known and new models and methods into a single system: 1) identification of the studied objects in the form of cognitive models of different levels of complexity, 2) analysis of the properties of models, 3) foreseeing (forecasting) options for the development of situations in the system on its model, 4) justification of decisions.

In the study, the results of which are presented in this article, the goal was for the first time to determine, using the cognitive modeling tools of complex systems, the possibilities and nature of the influence of informatization on the socio-economic development of the region. The general provisions and results of the study of the socio-economic system of the region, taking into account the possibilities of informatization, were concretized for the Republic of Dagestan in the Russian Federation. When studying the state of the republic, the tasks were set to predict its socio-economic development, subject to the development of information and communication technologies (ICT) and the development of an ICT management strategy.

Basic theoretical provisions of cognitive modeling of complex systems. Let us briefly present a number of information about the cognitive modeling of complex systems, which have been repeatedly presented in the author's works, for example [10–14, 23]. This is necessary for further presentation and explanation of the research results. Cognitive modeling of complex systems is a multi-stage cyclical research process. Its result is the presentation of the structure of a complex system in the form of a cognitive model of varying complexity (mathematically, this is a cognitive map — a sign oriented graph, vector sign digraph, functional digraph, etc.), analysis of the model's properties (structural properties, stability, sensitivity, etc.), anticipation of possible situations of development of events in the system in the form of various scenarios of development [1, 2, 7, 19].

The first stage is to develop a cognitive model based on the analysis of theoretical and practical knowledge in the studied subject area, based on the analysis of statistical data, according to expert polls.

The basis of any cognitive model is G — a cognitive map (1), which is the structure of a system consisting of a set of vertices $V=\{v_i\},\ i=1,2,...k$ and a set of relationships between them $E=\{e_{ij}\},\ i,j=1,2,..k$:

$$G=\langle V,E\rangle. \tag{1}$$

Model (1) fixes a set of cause-and-effect relations E between the main vertices — objects (concepts, entities, factors) of the set V of the complex system under study. In addition to the sets V and E, sets X of vertex parameters and characteristics of connections between the vertices can be defined in the form of weight coefficients ω_{ij} or functions $F_{ij}=f(x_i,x_j,e_{ij})$; in the latter case, the cognitive model is defined as a vector parametric functional graph [19].

The second stage of cognitive modeling of complex systems is the stage of studying the properties of the cognitive model (stability, connectivity, complexity, etc.). The presence of this stage makes cognitive modeling of complex systems, for example [10,11] different from traditional works on cognitive modeling of socio-economic and political systems, such as, for example [1–9,18–22].

The third stage is the stage of developing possible scenarios for the development of the system under the influence of changes in internal and external factors, control actions (situation management) [1, 2, 7, 19, 22, 25, 26]. To determine the processes of the development of situations on the model, the impulse process model is used [2, 7, 19]. Let us present it in the form [7, 10, 19]:

$$x_{v_i}(n+1)=x_{v_i}(n)+\sum_{v_j:e=e_{ij}\in E}^{k-1} f(x_i,x_j,e_{ij})P_j(n)+Q_i(n), \tag{2}$$

where $x_{vi}(n),\ x_{vi}(n+1)$ are the values of the indicator x_{vi} at the vertex v_i at the steps of the simulation at the moment $t=n$ and following it $t=n=1$; $P_j(n)$ is the magnitude of the impulse at the vertex v_j; $Q_j(n)$ is the vector of external disturbances introduced at the moment $t=n$.

The final fourth stage of cognitive modeling of complex systems is the stage of making decisions on the choice and subsequent implementation of the desired scenario for the development of a complex system.

Cognitive simulation is supported by the CMCS software system [23].

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As a result of the collection and processing of the existing practical material on the influence of informatization on the development of regions, it was possible to come to the conclusion about the lack of information about this influence; basically, such information is of a declarative nature. Therefore, an approach based on imitative cognitive modeling was chosen to obtain the missing information and clarify theoretical assumptions about the positive impact of ICT on the successful development of regions. Based on the generalization of existing data on the impact of ICT on socio-economic indicators, the main concepts (16 peaks) were selected and a cognitive map was developed (Fig. 1).

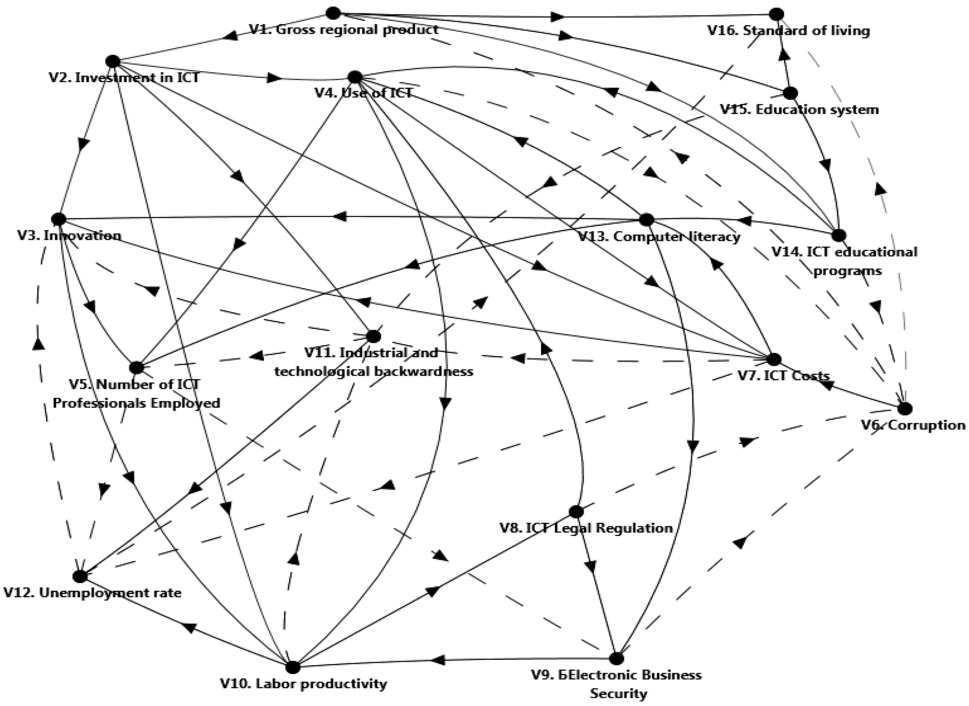

Fig. 1. Cognitive map G "Impact of ICT on the state of the region"

The implementation of all stages of cognitive modeling based on the cognitive map G (Fig. 1) and the analysis of the results obtained made it possible to use the G model as the basis for this study.

The purpose of the study of data on Dagestan was to determine the impact of digitalization on the development of Dagestan, to foresee the possible socio-economic development of Dagestan, subject to the development of ICT, and the subsequent development of an ICT management strategy that contributes to this.

Stage 1. Development of a cognitive model. At the initial stage, it was necessary to check the causal relationships between socio-economic indicators and the development of ICT in the Republic of Dagestan in accordance with model G. All values of the indicators were taken from information on the regional economy, as well as statistical data from the state statistics bodies of the Russian Federation and the Republic of Dagestan. The selected socio-economic indicators of the region are interrelated, affect each other to one degree or another, but in this study it was ICT indicators that played a key role in the study [15, 17, 22].

As such indicators, we have identified the following socio-economic indicators: GRP of Dagestan, Standard of living, Labor productivity, Industrial and technological backwardness, Corruption, Unemployment rate, Investment in ICT, Innovation, Use of ICT in organizations, Number of employed specialists in ICT, Expenses for ICT, Legal regulation of ICT, Electronic business security, Computer literacy, Educational programs in ICT, Dagestan Development Corporation.

Table 1 shows a fragment of data on the vertices of the cognitive map with a description of them and their role in the cognitive map, in table 2 — a fragment of data on the relationship between the vertices.

According to Table 1, each vertex has its own purpose: target, basic, control, disturbing. After identifying the peaks, it is necessary to establish causal relationships between them (a fragment of the description and explanation is presented in Table 2). The ratio between the vertices can be either positive, which corresponds to the “+” sign, or negative, the “-” sign.

The G1 cognitive map corresponding to Tables 1 and 2 is shown in Fig. 2.

Table 1. Tops of the cognitive map G1 “Digitalization of the Republic”

Code	**Vertex name**	**Explanation of vertex selection**	**Vertex assignment**
V1	GRP of the Republic	GRP is a generalized indicator of the development of the region. The Republic of Dagestan ranks 32nd in the rating of regions in terms of GRP in the Russian Federation	Target
V2	Investment in ICT	Investment in ICT is an investment of money on the development of ICT, it is an investment in fixed assets. A number of investment projects are outlined in the republic ... The costs of ICT in the republic are low and very unstable	Manager (entrance)
…			
V4	Use of ICT	According to Rosstat, the use of information and communication technologies in the organizations of the republic is low, as well as the average share of expenditures on ICT ...	Indicative (output)
…			
V6	Corruption	There is corruption in the government, the clan and ethnic nature of power, hinders the real development of ICT	Basic
…			
V12	Unemployment rate	The republic has favorable demographic trends, but an unfavorable socio-economic situation, which contributes to the growth of the unemployment rate	.Outrageous
…			
V15	Development Corporation	By the Decree of the President of the Republic of July 22, 2013 No. 208, a Corporation for the Development of Dagestan was created in the republic, the main goal of which is the implementation of innovative projects	Manager
V16	Living standard	The poverty level in 2018 was 15,1% compared to the previous year (almost 500 thousand people). ... In terms of the “average size of pensions” indicator, the region is on the 85th (last) place. The republic ranks 83rd in the country in terms of family welfare	Target (output)

T a b l e 2 . Causal relationships (relationships) between the vertices of the cognitive map G “The impact of digitalization on the main indicators of the development of the Republic”

Code	Vertex-cause	Vertex-effect	Explanation of the relationship	Sign
$e_{1,3}$	V1. GRP of the Republic	V3. Investments	Investments in fixed assets can be classified as significant indicators affecting GRP. In the republic, investments mainly go to residential buildings and premises, but more investment in information and communication technologies (ICT) is needed	+
$e_{1,14}$		V14. Educational programs on ICT	Growth of GRP affects the implementation of educational programs on ICT	+
$e_{1,16}$		V16. Living standards	An increase in GRP increases the living standards and well-being of people.	+
…				
$e_{15,4}$	V15. Development Corporation of the Republic	V4. Use of ICT	Dagestan Development Corporation provides its platform for the promotion of ICT projects	+
$e_{15,5}$		V5. Number of employed ICT	specialists Attracts investors and ICT specialists to cooperation	+
$e_{15,7}$		V7. ICT costs	ICT costs have a beneficial effect on corporate innovation projects	+
…				

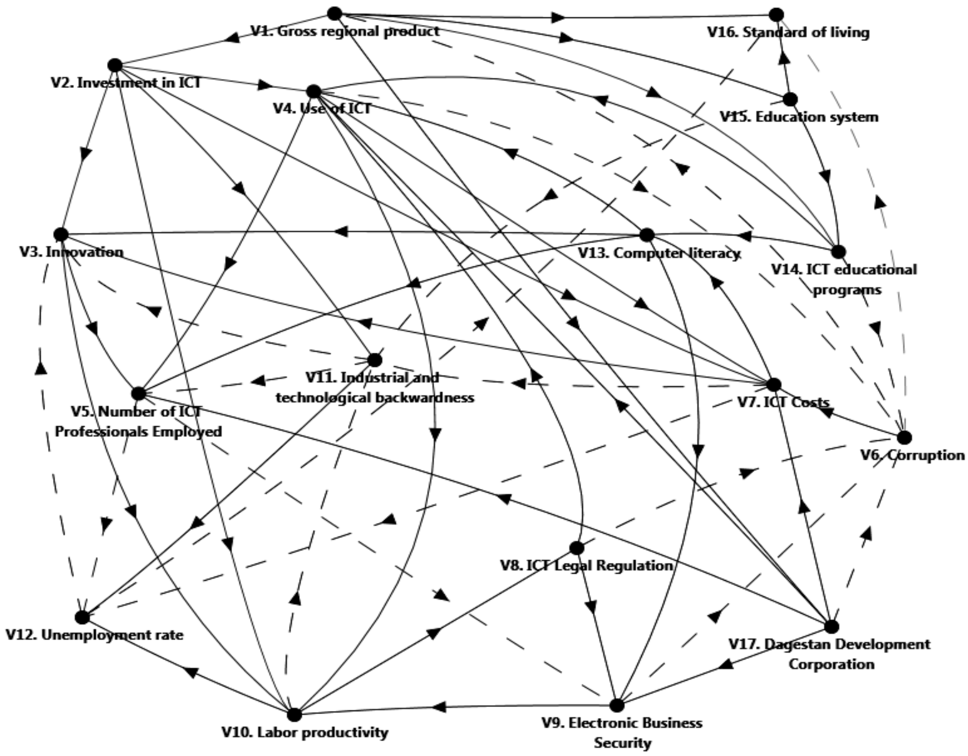

Fig. 2. Cognitive map G1 “Digitalization of the republic”

Stage 2. Analysis of the properties of the cognitive map G1 “Digitalization of the Republic of Dagestan”.

1. *Determination of the degree of the vertices of the graph G1*. The analysis of the degrees of the vertices of a cognitive map is carried out in order to determine the role of each vertex in the structure of the system according to its influence (or influence on it) on the entire system and to select the vertices that are most significant in terms of the number of incoming and outgoing arcs. This is necessary, among other things, to select the vertex to which it is most desirable to make changes. Fig. 3 shows the results of the corresponding calculations.

Graph properties

Vertices: 17. Edges: 53.

Vertex	p	p+	p-
V2. Investment in ICT	6	1	5
V3. Innovation	7	5	2
V4. Use of ICT	9	5	4
V5. Number of ICT Professionals Employed	7	5	2
V6. Corruption	8	5	3
V8. ICT Legal Regulation	4	1	3
V9. Electronic Business Security	6	4	2
V12. Unemployment rate	6	4	2
V13. Computer literacy	6	2	4
V14. ICT educational programs	5	2	3
V16. Standard of living	4	4	0
V7. ICT Costs	8	4	4

Fig. 3. Determination of the degrees of vertices *G*1

As can be seen from Fig. 3, the top V4. Use of ICT can be considered the most significant $(p = 9)$, significantly affecting the entire system (the number of outgoing arcs, half-degree $p- = 4$). Information about the degree of vertices can also be used when selecting vertices to which changes will be made during modeling scenarios.

2. *Analysis of paths of the graph G1*. Using the CMCS software system [22], it is easy to analyze all possible paths from any vertices of the graph. Fig. 4 shows one of the options for paths from the top of V15.Education System to the top of V4.Use of ICT, i.e. the paths of V15 impact on V4 are analyzed. There are more than 200 such paths. In Fig. 4, only one of the positive paths is marked (a "positive path" is a path in which there are no or an even number of negative arcs). It can be interpreted as going from top to top. Fig. 5 shows the path

$$V_{15} \to V_{14} \to V_6 \to V_7 \to V_{13} \to V_4$$

a simpler version of the transition from V15 to V4 (to facilitate the process of interpretation in the article): the top of V15. The Education System has a "positive" effect on the top of V14. ICT educational programs, this leads to a weakening of the V6 top. Corruption, weakening Corruption leads to positive changes in the sequential chain of V7.ICT Costs, V13.Computer literacy and V4.Use of ICT.

3. *Analysis of the cycles of the cognitive map*. In Fig. 6 shows the results of determining the cycles of the cognitive map G1 and highlights one of its negative and positive cycles.

In total, there are 589 cycles in the G1 model, of which 159 are negative and 430 are positive. Positive feedback loops are loops with no or even number of negative arcs; these are cycles of accelerators of processes in the system. Negative feedback loops are loops with an odd number of negative arcs. These are stabilizer cycles.

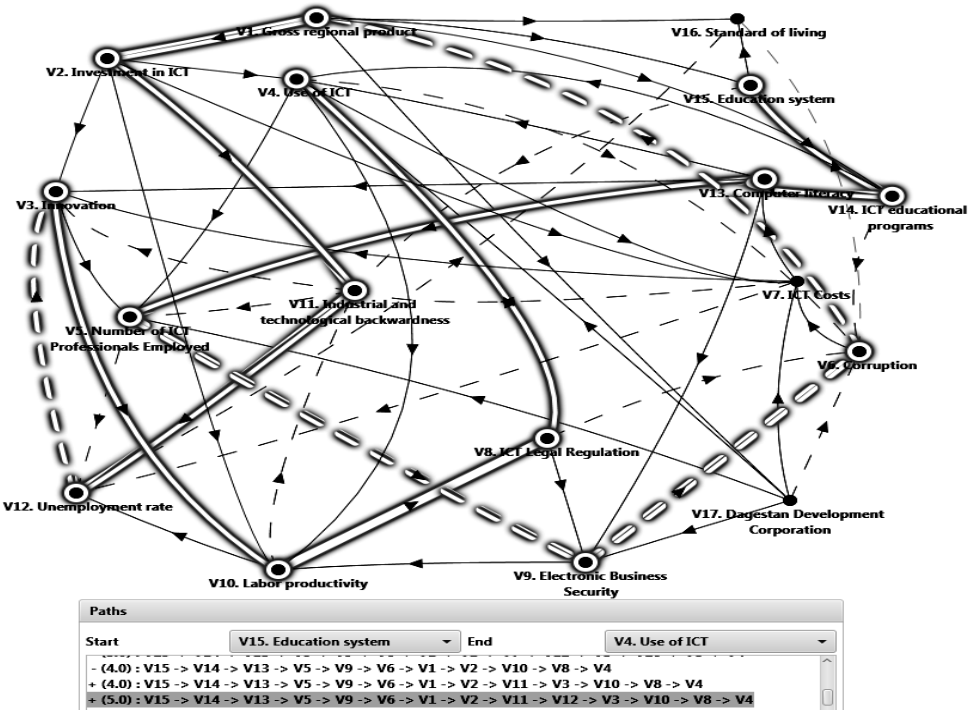

Fig. 4. One of the positive paths from V15 to V4

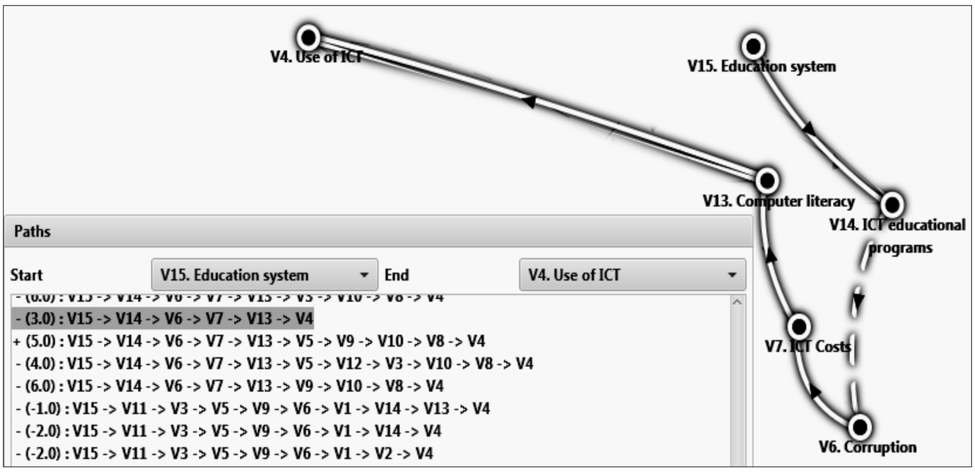

Fig. 5. One of the negative paths from V15 to V4

As well as in the analysis of the paths (cause-effect chains) of a cognitive map, the analysis of the cycles of the model reveals the contradiction / non-contradiction of its theoretical and practical information about the system under study and accordingly corrects the model. In addition, cycle analysis allows you to determine the structural stability of the model.

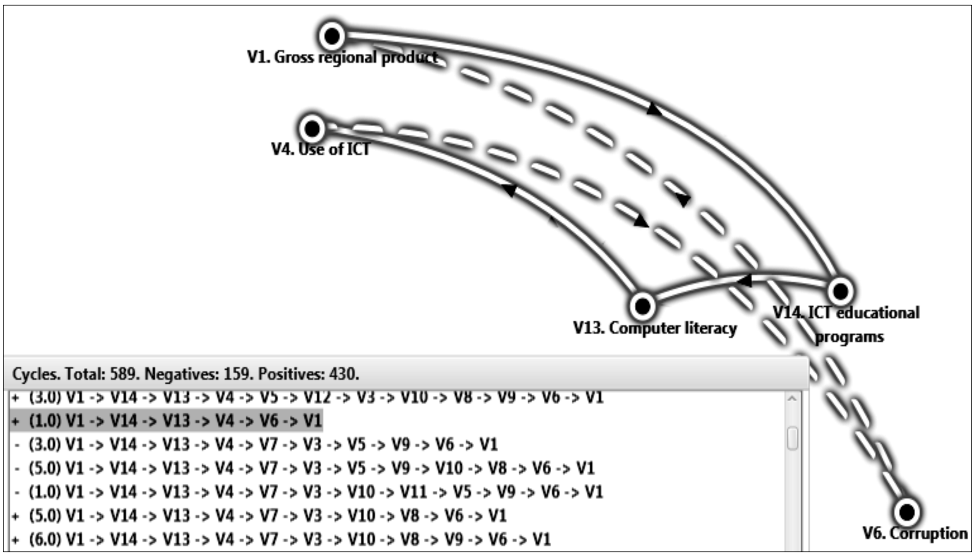

Fig. 6. Highlighting the cycles of the cognitive map G1

4. *Analysis of structural stability and stability of the model to disturbances.*

The analysis of structural stability is carried out according to the results of determining the cycles of the cognitive map [3, 10, 24, 25]. If the model has an odd number of negative cycles, then it is considered structurally stable. In this case, there is structural stability, since there are 159 negative cycles in the system.

The analysis of stability to disturbances and by the initial value is carried out according to the results of calculating the roots of the characteristic equation of the matrix of relations RG cognitive map [7, 8, 10, 14]. For stability, it is necessary that the largest modulo number of the characteristic equation of the matrix of relations be less than one. Fig. 7 shows the result of calculating the roots RG1. Since $|M| = 1{,}92 > 1|$ the system is not stable to disturbances.

Eigenvalues			
#	Real part	Imaginary part	Module (1.9236)
0	1.9236	0.0	1.9236
1	-0.976	1.3926	1.3926
2	-0.976	-1.3926	1.3926
3	1.4671	0.0	1.4671
4	-0.0366	1.3852	1.3852
5	-0.0366	-1.3852	1.3852
6	0.5057	0.8212	0.8212
7	0.5057	-0.8212	0.8212
8	-0.858	0.0	0.858
9	-0.6639	0.4091	0.6639
10	-0.6639	-0.4091	0.6639
11	-0.0956	0.5038	0.5038
12	-0.0956	-0.5038	0.5038
13	0.0	0.0	0.0
14	0.0	0.0	0.0
15	0.0	0.0	0.0
16	0.0	0.0	0.0

Fig. 7. Calculation of the roots of the characteristic equation of the matrix RG1

Stage 3. Scenario modeling. Modeling of scenarios of possible development of situations is carried out by means of impulse modeling [7, 19, 21, 23], formula (2). The CMCS software system [23] allows impulse modeling by introducing perturbations into one, two or more vertices of the model; the impulse value can be greater or less than 1 (at the beginning of the study it is recommended to set the impulse $q=+1$ or $q=-1$) and be applied at the initial or any other simulation cycle. In the article, we present the results of impulse modeling for three fairly indicative scenarios.

Scenario 1. Let the use of ICT begin to increase in the republic, which is imitated by introducing a perturbation into the vertex V4. Use of ICT (impulse $q_4=+1$), a vector of perturbations $Q=\{q_1=0,\dots,q_4=+1,\dots,q_{17}=0\}$.

The calculation results are shown in Table 3 and Fig. 9.

Table 3. Results of the computational experiment, Scenario 1

Vertex	Step										
	0	1	2	3	4	5	6	7	8	9	10
*V*1. GRP of the Republic	0	0	0	1	1	1	7	6	13	46	42
*V*2. Investment in ICT	0	0	0	0	1	1	1	7	6	13	46
*V*3. Innovation	0	0	0	1	4	4	12	25	37	90	165
*V*4. Use of ICT	0	1	1	1	3	5	7	20	32	51	136
*V*5. Number of ICT Professionals Employed	0	0	1	1	5	9	12	39	61	103	265
*V*6. Corruption	0	0	-1	-1	-1	-7	-6	-13	-46	-42	-109
*V*8. ICT Legal Regulation	0	0	0	1	1	1	9	7	14	56	52
*V*9. Electronic Business Security	0	0	0	-1	1	-3	-6	4	-23	-30	0
*V*12. Unemployment Rate	0	0	0	-1	-2	-5	-5	-18	-35	-43	-126
*V*13. Computer Literacy	0	0	0	1	0	1	6	2	11	34	17
*V*14. ICT Education Programs	0	0	0	0	1	2	2	8	13	19	59
*V*16. Standart of Living	0	0	0	1	3	5	14	19	44	100	144
*V*7. ICT Costs	0	0	1	0	0	4	0	3	21	-2	35
*V*10. Labor Productivity	0	0	1	1	1	9	7	14	56	52	124
*V*11. Industrial and technological backwardness	0	0	0	-2	-1	-1	-13	-7	-17	-77	-50
*V*15. Education System	0	0	0	0	1	1	1	7	6	13	46
*V*17. Dagestan Development Corporation	0	0	0	0	1	1	1	7	6	13	46

According to Table 3, graphs of impulse processes and a histogram of impulse values at 7 simulation steps are constructed — Fig. 8. Impulse modeling can be carried out until the tendency of possible development of situations in the system is clearly manifested.

Scenario 2. Let the Dagestan development corporation begin to function in the republic, which is modeled by the introduction of a control impulse $q_{17}=+1$ into the top of V17; vector of perturbations. The graphs based on the calculation results are shown in Fig. 9.

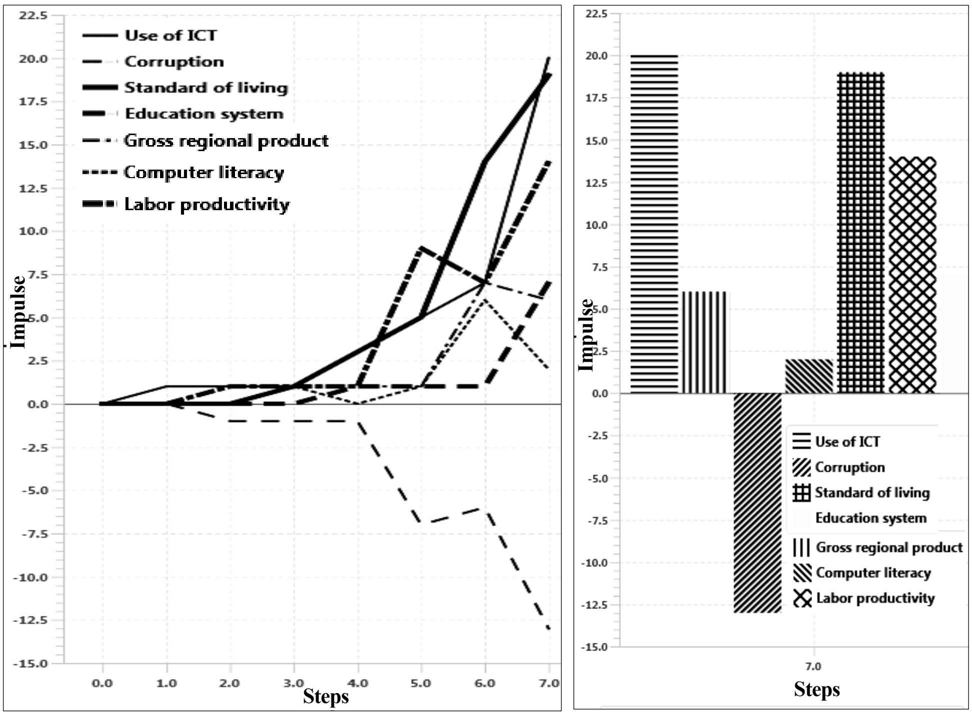

Fig. 8. Impulse Simulation. Scenario 1

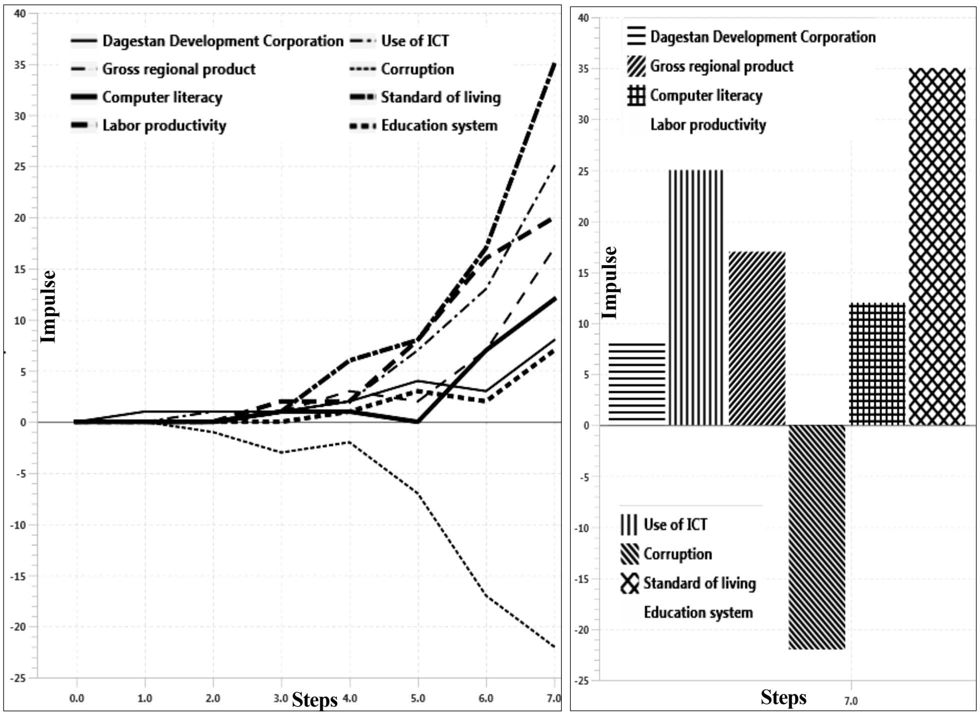

Fig. 9. Impulse Simulation. Scenario 2

Scenario 3. Let corruption increase in the republic, but the Dagestan development corporation begins to function and Labor productivity grows; vector of perturbations:

The graphs based on the calculation results are shown in Table 4 and in Fig. 10.

Table 4. Results of the computational experiment, Scenario 3

Vertex	Step										
	0	1	2	3	4	5	6	7	8	9	10
*V*1. GRP of the Republic	0	0	-1	0	3	2	3	11	19	45	68
*V*2. Investment in ICT	0	0	0	-1	0	3	2	3	11	19	45
*V*3. Innovation	0	0	0	2	9	9	10	33	66	106	200
*V*4. Use of ICT	0	0	1	2	1	4	12	24	38	62	156
*V*5. Number of ICT Professionals Employed	0	0	1	3	9	17	17	39	95	147	287
*V*6. Corruption	0	1	0	-3	-2	-3	-11	-19	-45	-68	-114
*V*8. ICT Legal Regulation	0	0	1	1	3	5	11	13	14	61	107
*V*9. Electronic Business Security	0	0	1	1	0	-4	-11	0	-9	-58	-40
*V*12. Unemployment Rate	0	0	1	-3	-5	-7	-9	-23	-52	-66	-129
*V*13. Computer Literacy	0	0	0	2	1	-3	3	13	11	26	46
*V*14. ICT Education Programs	0	0	0	-1	-1	3	5	5	14	30	64
*V*16. Standart of Living	0	0	-1	-2	5	10	15	25	56	127	198
*V*7. ICT Costs	0	0	2	2	-2	0	8	6	12	16	33
*V*10. Labor Productivity	0	1	1	3	5	11	13	14	61	107	130
*V*11. Industrial and technological backwardness	0	0	-1	-3	-5	-3	-11	-21	-20	-73	-123
*V*15. Education System	0	0	0	-1	0	3	2	3	11	19	45
*V*17. Dagestan Development Corporation	0	1	1	0	1	4	3	4	12	20	46

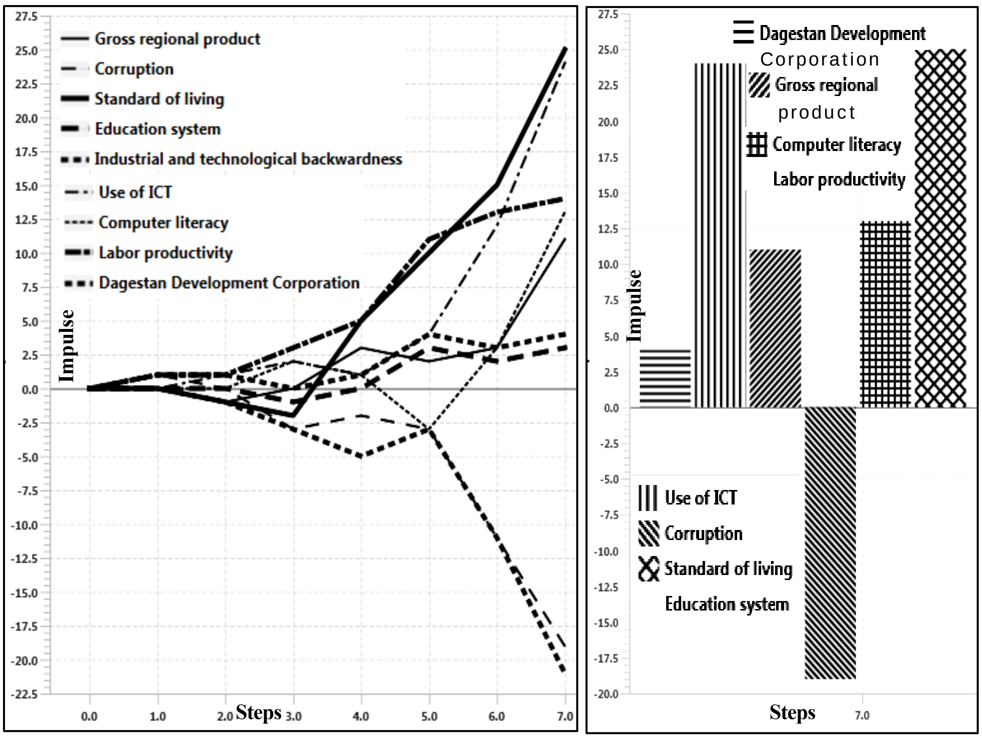

Fig. 10. Impulse Simulation, Scenario 3

The considered scenarios are not the only ones possible in this system; in the course of the study, various options were considered when disturbing one, two, three or more vertices.

As can be seen from the results of impulse modeling (Tables 3 and 4, as well as Fig. 8–10), all scenarios indicate the same type of "positive" development of events in the "Digitalization of the Republic" system, displayed by the cognitive map G1. When making control actions to the top V4.Use of ICT, then to the top V7.Dagestan development corporation, then immediately to three vertices V7. Dagestan development corporation, V10.Labor productivity, V4.Corruption, there are tendencies of increase in the analyzed socio-economic indicators: GRP of Dagestan, Living standards, Unemployment rate, Investment in ICT, Innovation, ICT use in organizations, Number of employed specialists in ICT, ICT spending , ICT Legal Regulation, Electronic Business Security, Computer Literacy and ICT Education Programs while Reducing Corruption and Industrial and Technological Backwardness.

The above examples confirm the assumption that the development of ICT in the Republic of Dagestan and the adoption of an organizational decision to create the Dagestan Development Corporation for this purpose should bring positive results in improving the living standards of the population, improving the education system.

CONCLUSION

The methodology of cognitive modeling of complex systems, including the SMC toolkit, is a convenient means of not only understanding, explaining, and anticipating the possible development of a complex system (socio-economic, ecological, political, socio-technical, etc.), but also formalizing the corresponding cognitive processes. The latter makes it possible to diversify a complex system much deeper and more fully than can be done by traditional methods and in conditions of incomplete information. This is illustrated

The article discusses topical issues of the influence of informatization on the development of regions on models such as cognitive maps. Further studies of the influence of ICT on the socio-economic indicators of the republic are aimed at the development of mathematically more complex cognitive models, including functional dependencies between some peaks of cognitive maps.

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Received 09.08.2021

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КОГНИТИВНОЕ МОДЕЛИРОВАНИЕ ВЛИЯНИЯ ИНФОРМАТИЗАЦИИ НА СОЦИАЛЬНО-ЭКОНОМИЧЕСКИЕ ПОКАЗАТЕЛИ РЕГИОНА / Г.В. Горелова, С.Р. Магомедова, С.А. Фейламазова

Аннотация. Рассмотрены актуальные вопросы влияния информатизации на развитие регионов страны в условиях современного нестабильного мира. Характер развития региона может отражаться и пониматься на основании качественной и количественной информации о его социально-экономических показателях, об их взаимосвязи и тенденций их изменений под влиянием внутренних и внешних факторов. При этом информация чаще всего может быть неполной, трудно доступной, несвоевременной, противоречивой и т.п. Поэтому в работе предложено использовать когнитивный подход и когнитивное моделирование сложных систем для преодоления проблем информационной недостаточности путем имитационного когнитивного моделирования структуры и поведения сложной региональной системы. Имитационное моделирования проводилось с помощью авторской программной системы CMCS (Cognitive Modeling Complex System). Приведены результаты многоэтапного когнитивного моделирования, состоящего в разработке когнитивных карт «Влияние ИКТ на состояние региона» и «Цифровизация республики» (по данным социально-экономического состояния республики Дагестан), анализа структурных свойств и моделирования сценариев развития ситуаций на модели. Сценарии позволяют предвидеть пути возможного развития системы под воздействием разных факторов, в том числе — фактора информатизации.

Ключевые слова: сложные системы, исследование, когнитивное имитационное моделирование, регион, информационно-коммуникационные технологии.

КОГНІТИВНЕ МОДЕЛЮВАННЯ ВПЛИВУ ІНФОРМАТИЗАЦІЇ НА СОЦІАЛЬНО-ЕКОНОМІЧНІ ПОКАЗНИКИ РЕГІОНУ / Г.В. Горєлова, С.Р. Магомедова, С.А. Фейламазова

Анотація. Розглянуто актуальні питання впливу інформатизації на розвиток регіонів країни в умовах сучасного нестабільного світу. Характер розвитку регіону може відображатися і розумітися на підставі якісної і кількісної інформації про його соціально-економічні показники, їх взаємозв’язки і тенденції їх змін під впливом внутрішніх і зовнішніх факторів. При цьому інформація найчастіше може бути неповною, важкодоступною, несвоєчасною, суперечливою і т. ін. Тому у праці запропоновано використовувати когнітивний підхід і когнітивне моделювання складних систем для вирішення проблем інформаційної недостатності шляхом імітаційного когнітивного моделювання структури і поведінки складної регіональної системи. Імітаційне моделювання виконувалось за допомогою авторської програмної системи CMCS (Cognitive Modeling Complex System). Наведено результати багатоетапного когнітивного моделювання, що складається з розроблення когнітивних карт «Вплив ІКТ на стан регіону» і «Цифровізація республіки» (за даними соціально-економічного стану республіки Дагестан), аналізу структурних властивостей і моделювання сценаріїв розвитку ситуацій на моделі. Сценарії дають змогу передбачити перспективу розвитку системи під впливом різних факторів, в тому числі — фактора інформатизації.

Ключові слова: складні системи, дослідження, когнітивне імітаційне моделювання, регіон, інформаційно-комунікаційні технології.