Regional Competitiveness Research Based on Digital Models Using Kolmogorov-Chapman Equations

Irina Veshneva, Galina Chernyshova, and Alexander Bolshakov

Abstract The concept of regional competitiveness is investigated taking into account the trends in the transition to Industry 4.0. The risk indicators analysis for the competitiveness increase of Russian regions was carried out. A systematization of indicators based on a cause-effect graph was proposed. The developed system of indicators allows us to identify competitive risks at the regional level. A simplified digital model of the cause-effect graph structure for competitiveness risks was presented. It is suggested to find a solution to the problem of high dimension by revealing the structures of minimal cut set in a causal graph. In this case, it is assumed that the reasons that trigger the chain of event-consequences realization which leads to the risk of a root event of the cause-effect graph should be identified. The minimal cut sets for the obtained graph of competitiveness factors that correspond to critical combinations of events and lead to a decrease in the region's competitiveness were determined. The digital model was validated using the indicators values for the regions of the Volga Federal District as an example.

Keywords Digital model · Industry 4.0 · Cyber-physical systems · Competitiveness · Regions of the Russian federation · Cause-effect graph · Minimal cut set · Kolmogorov-Chapman equations

I. Veshneva (✉) · G. Chernyshova
Saratov National Research University named after N.G. Chernyshevsky, 83, Astrakhanskaya Street, Saratov 410012, Russia
e-mail: veshnevaiv@gmail.ru

G. Chernyshova
e-mail: cherny111@mail.ru

A. Bolshakov
Peter the Great St. Petersburg Polytechnic University, 29, Polytechnicheskaya, St. Petersburg 195251, Russia
e-mail: aabolshakov57@gmail.com

A. G. Kravets et al. (eds.), *Society 5.0: Cyberspace for Advanced Human-Centered Society*, Studies in Systems, Decision and Control 333,
https://doi.org/10.1007/978-3-030-63563-3_12

1 Introduction

In the context of the transition to Industry 4.0, the competitiveness of regions or other territorial items is an urgent issue concerning creating and studying the risks of adverse events, and their consequences. The concept of regional competitiveness has different ambiguous definitions. In many cases, the proposed interpretations correspond to the requirements of the specific research. The competitiveness of the region is a reflection of the complex interaction of various factors (economic relations, productive forces, institutional environment), and from such interaction, a synergistic effect appears.

Traditionally, for quantitative evaluation of competitiveness at the country level is applied to the gross domestic product (GDP). For a comprehensive assessment of regional development, Russian statistical sources use an indicator such as the gross regional product. Competitiveness can be interpreted in terms of efficiency, which is expressed through GDP, and industrial indicators of the region. However, the GDP as an indicator of wealth and economic development has been criticized [1].

A large number of competitiveness assessments apply a rating approach. One of the main theories, which is devoted to the study of regional competitiveness and its relationship with the characteristics of global competitiveness, was proposed by M. Porter. His concept is based on the method of determining the so-called global competitiveness indicator. It can be used to control the competitiveness of a particular region [2].

Application of the principles of cyber-physical systems creating is essential for obtaining modern models for assessing socio-economic objects. The estimations obtained using the Global Competitiveness Index (GCI) 4.0 reflect the ability of countries to compete in the era of the Fourth Industrial Revolution [3]. Indicators considered as prerequisites for long-term growth are united in a hierarchical structure containing four categories: the creation of favorable institutional, infrastructural conditions; human capital; innovation ecosystem; development of commodity markets, financial system.

The European Regional Competitiveness Index (RCI) provides a generalized submission of competitiveness for each of the territorial nomenclature units. Although RCI includes a wide set of indicators, it has some limitations, for example, it does not take into account any of the environmental aspects [4].

The Global Sustainable Competitiveness Index (GSCI) involves an extensive range of indicators, taking into account factors of sustainable development and future potential (environment, society, economy) for integrated competitiveness assessing [5].

Other proposed approach includes a large number of factors which affect regional system performance. These indicators are divided into three groups: social infrastructure and political institutions, monetary and fiscal policies, microeconomic competitiveness. This structure covers more than 120 indicators [6, 7].

A modern approach to competitiveness estimation is associated with innovations and new production technologies, including cyber-physical systems. They lead to the growth of industrial production without increasing damage to the environment. In the framework of the World Economic Forum methodology, competitiveness estimation is formulated in terms of environmental sustainability. The efficient use of natural resources; health improvement; biodiversity for innovation are taken into account. As a rule, Green economies work better in terms of the labor force health (reduction of environmental pollution), innovation, and restoration of natural capital [8].

Significant attention is devoted to studies of the economy cluster composition. It is concluded that increasing competitiveness should have a cluster character. This point of view differs from the previous provisions on the targeted nature of industrial production. It means the economy gradually moves to related activities that rely on the corresponding fundamental comparative advantages [9, 10].

An essential aspect of the conceptual approach to regional competitiveness is the increase in labor productivity and innovative activity [11]. A distinctive feature of regional competitiveness models should ensure the inclusion of endogenous growth patterns. Key factors requiring targeted investments are human capital and knowledge. They will determine the differences in growth rates according to researchers [12].

It is especially important to give due consideration to the effectiveness of using the principles of cyber-physical systems constructing for managing socio-economic processes. To analyze the scientific, technical and innovative potential of the region in the process of assessing competitiveness, especially the interaction of innovations and socio-economic development of territories, it is necessary to take into account the specifics of assessing competitiveness in various conditions, especially the interaction of innovation and socio-economic development of territories [13].

The debatability of the methodology for assessing regional competitiveness has led to the emergence of a variety of ratings comparing the Russian regions by different sets of indicators. However, competitiveness is not a characteristic that can be measured directly; assessments are based on an indirect set of indicators. Econometric models have significant limitations in the process of application (formulation of a hypothesis about the nature of data distribution, sampling of the required volume, quantitative indicators, unstructured time series). Attempts to use artificial intelligence methods and models to expand the possibilities of numerical assessment of complex socio-economic systems in the face of uncertainty, and inaccuracy of information are limited to simpler objects of study than the competitiveness of regions. The proposed approach will allow the development of constructive digital mathematical models and methods for the dynamic assessment of the risks of competitiveness of the Russian regions on the principles of building cyber-physical systems.

2 Formation of a Risk Factors Hierarchical Structure for Regional Competitiveness Assessment

Digital modeling of regional competitiveness involves specifying the concept under consideration. In the context of the regional economy, there are different approaches to competitiveness. As an important criterion for this category, the ability of regional authorities to create conditions for achieving and maintaining a competitive advantage in certain areas is highlighted [14].

The experience of foreign studies cannot be fully applied to the Russian regions due to the specifics of the Russian economy. The development of the domestic regional economy is largely determined by differences in the conditions of reproduction: the regions are provided with natural resources to varying degrees; differ in climatic, social, economic, investment, and innovative conditions [15]. For a systematic assessment concerning identifying the risks of regional development, competitiveness is determined by the ability to use regional potential (resource, raw materials, labor, innovation, production) to achieve high living standards.

Risk is an integral part of the functioning of socio-economic systems at any level. Therefore, the risks have a significant impact on the governance of competitiveness, require consideration in the formation of managerial decisions. Existing approaches to the definition of risk concerning socio-economic systems focus on the uncertainty and probabilistic nature of the assessment. In particular, this refers to the probability of obtaining an unpredictable result as a consequence of a management impact. It should be noted that the risk is a real or perceived event or activity that could potentially cause uncertainty, harm, or destruction of the economic, natural, or social system [16].

The risks of regional competitiveness are understood as the risk of negative trends that arise in the process of socio-economic development as a result of an unsatisfactory degree of taking into account various types of dangers. These dangers threaten regional socio-economic development if the corresponding managerial influences were not appropriated during creating the concept of perspective directions for regional development and strategic management.

An important research stage is the formation of an indicator set to assess the regional competitiveness risks. The methods used for the quantitative estimation of regional competitiveness are diverse in the indicator set. They generally contain such categories as macroeconomic, infrastructural, demographic, technological, and innovative indicators. For a systematic assessment of competitiveness risks, it is necessary to include in the model a sufficiently large number of external (economic, political, organizational) and internal (financial and non-financial) factors that create threats at the regional level. Studies that do not take into account various aspects of competitiveness and their interaction do not provide the necessary tools to support decision-making at the territorial level [17]. Therefore, the application of ideas and methods for constructing cyber-physical systems for a given subject area is relevant.

To understand the phenomenon of competitiveness, various factors of competitiveness risks are highlighted by the proposed classification. They are presented as a hierarchical structure. The root level of the tree corresponds to the integral assessment of regional competitiveness. At the next level of the hierarchy, two categories of indicators are distinguished: transactional and transformational factors. The applied method of event tree formation allows distinguishing semantically connected groups of indicators [18].

Technical, social, and natural resource risk indicators are denoted as transformational indicators at the next level of the event tree. The category of transactional indicators includes institutional, informational, and innovative indicators of competitiveness risks. An expanded set of indicators is presented for a comprehensive description of the regional competitiveness risk system at the next level of the hierarchical structure. As the leaves in the tree-like structure, it is proposed to use an extended set of characteristics: the value of all fixed assets; the value of fixed assets depreciation; the density of railway tracks; density of paved roads; the percentage of the population with money income below the subsistence minimum; average per capita money income of population; life expectancy at birth; migration growth coefficient; dilapidated housing stock; the number of medical personnel (doctors) per 10,000 population; the number of unemployed registered at the bodies of employment services; the number of recorded crimes; the volume of shipped own-produced goods, works performed and services (mining and quarrying); sowing areas of main crops; emission of pollutants into atmosphere; discharge of polluted sewage; use of the Internet electronic documentary exchange in organizations; R&D personnel; sales of innovative goods and services. This set of indicators sufficiently describes the level of regional development and allows assess the competitiveness risks. Besides, statistical data is available, and corresponding data has been collected for a fairly long time.

3 Building an Event Tree to Prevent Competitiveness Risks at the Regional Level

The proposed method to the analysis of risks associated with a decrease in the competitiveness of regions is to study the factors of competitiveness risks based on the formed causal graph. A special feature of the method is the development of a cross-functional tree graph to describe a complex multi-factor object, which is the competitiveness of the region. The use of cause-effect graphs has been well tested in the analysis of technical systems. The extension of these methods has been demonstrated for the analysis of socio-economic systems and cyber-physical systems. It can be argued that the systematization of competitiveness indicators for Russian regions based on the structures of cause-effect graphs is promising.

To modeling the structure of the cause-effect graph for systematization of competitiveness risk indicators, the following hierarchical risk indicators system of for assessment is proposed: regional competitiveness (E_0); transformational (E_1); transactional (E_2); technical (E_3); social (E_4); natural resource (E_5); institutional (E_6);

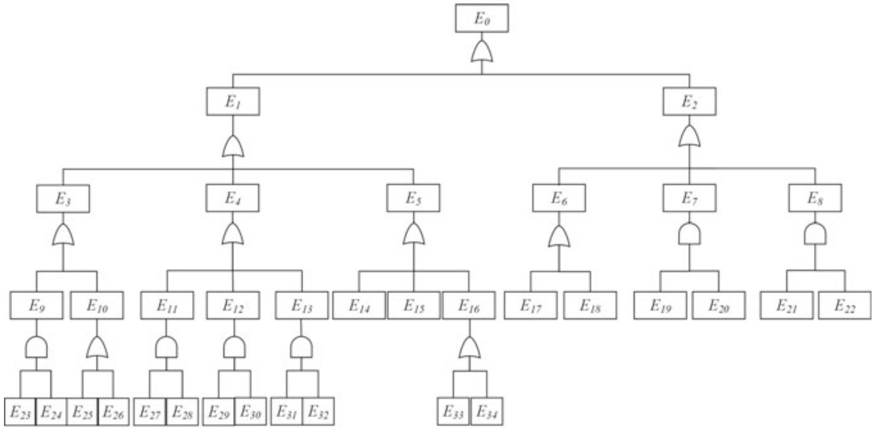

Fig. 1 The hierarchical structure of the region competitiveness risk indicators

information (E_7); innovative (E_8); using of fixed assets (E_9); transport infrastructure (E_{10}); population income (E_{11}); demographic (E_{12}); quality of life (E_{13}); mineral extraction (E_{14}); sowing areas of main crops (E_{15}); environmental (E_{16}); number of unemployed (E_{17}); number of crimes (E_{18}); using of the Internet (E_{19}); using the Internet electronic documentary exchange in organizations (E_{20}); R & D personnel (E_{21}); sales of innovative goods and services (E_{22}); all fixed assets (E_{23}); fixed assets depreciation (E_{24}); density of railway tracks (E_{25}); density of paved roads (E_{26}); average per capita money income of population (E_{27}); the percentage of the population with money income below the subsistence minimum (E_{28}); life expectancy at birth (E_{29}); migration growth coefficient (E_{30}); dilapidated housing stock (E_{31}); medical personnel (doctors) per 10,000 population (E_{32}); emission of pollutants into atmosphere (E_{33}); discharge of polluted sewage (E_{34}). Figure 1 shows a causal graph for assessing regional competitiveness risks.

Digital modeling based on the obtained structure allows identifying a key direction for management decision making that impact on the socio-economic system of the region to increase its competitiveness.

4 Kolmogorov-Chapman Model for Assessing Competitiveness Risks

The following algorithm, taking into account the values of the vector of managerial influences on the set of adverse events $u(t) \in U$ is used to assess the competitiveness of a particular region. For permissible values of the vector of estimation of the states of the system $x(t) \in X$ the criterion is minimized at a given time interval $[t_s, t_f]$:

$$K_A = \int_{t_s}^{t_f} Pr(t, x, u)\mathrm{d}t, \quad (1)$$

где K_A is the criterion which characterizes the risks of reducing the region's competitiveness in the time interval $[t_s, t_f]$; Pr is the probability of the corresponding risk being realized and the occurrence of a certain process stopping due to a critical combination of events under consideration, while they do not separately cause the specified risk; X, U are a set of values for system state vectors $x(t)$ and management impacts on the combination of adverse events $u(t)$; the variable t indicates time.

The solution to this task poses certain difficulties because the construction of a sufficiently complex digital mathematical model for the active system under research is required for a full procedure for determining the values of the criterion $K_A(t, x, u)$ as well as the integrand $Pr(t, x, u)$. In the process of minimization, it is necessary to solve a complex system of differential equations of relatively high dimension. Thus, when solving the formulated problem, it is required to determine the control action $u(t) \in U$ which transfers the criterion value K_A into the area of the minimum risk probability for the vertices of the constructed cause-effect graph. In this regard, the basis of the algorithm contains a statement repeatedly confirmed by practice that to reduce the risks of the root event at the top of the graph, it is enough to develop and implement a detailed comprehensive plan of action for minimizing the selected combinations of risks.

As a result, task (1) is reduced to the search for such actions to achieve effective functioning of the region's competitiveness management system, in which the probability of occurrence and development of risks to reduce the region's competitiveness is minimized.

To assess the probability of the occurrence of a possible set of events that are atomic in the proposed representation, it is necessary to single out a finite number of states. The state graph for the complete cause-effect tree of events (Fig. 1) has 2^{35} = 34 359 738 368 vertices corresponding to the combinations of events. Solving a system of more than 34 million equations is not feasible. It is possible to consider mathematical models of separated fragments of the tree structure. These parts are formed by the minimal cut sets structure for the cause-effect graph.

To assess the probability of reducing competitiveness, the minimal cut sets [19] of the graph of the main factors affecting competitiveness are determined. Elements of these minimal cut sets correspond to groups of processes, the implementation of risks of non-fulfillment of which leads to the loss of competitiveness by the region. Classification is performed by the number of elements of minimal cut sets. There are two-, three-element, etc. minimal cut sets. They correspond to combinations of events that are critical and lead to a decrease in the competitiveness of the Russian region.

A state graph is formed for each such section, which is used to construct a system of differential equations. Such a system is called Kolmogorov-Chapman [20, 21]. As a result of solving the system of differential equations the probability of reducing the region's competitiveness due to critical combinations of events associated with individual risk factors is determined.

Let us consider one variant of the minimal cut sets E_{17}—E_{19}—E_{20}—E_{21}—E_{22}. This minimal cut set is 5-element; it includes innovative, institutional, and informational risk factors for regional competitiveness. Possible causes of adverse events or the implementation of risks are presented in Fig. 2. The implementation of each risk combination is characterized by the probability $Pr_{\mathrm{i.}}$ Analysis of the state graph of the type shown in Fig. 2 can be performed by digital mathematical modeling methods.

For each of the states, it is necessary to compose a differential equation:

$$\frac{\mathrm{d}Pr_i(t)}{\mathrm{d}t} = \sum_{j=0}^{31} l_i Pr_j(t) - \sum_{k=0}^{31} d_k Pr_k(t) \tag{2}$$

The constraints are formed based on the Kolmogorov-Chapman differential equations system and in matrix form have the following form:

$$\frac{\mathrm{d}Pr(t)}{\mathrm{d}t} = A \cdot \begin{pmatrix} Pr_0(t) \\ Pr_1(t) \\ \dots \\ Pr_{32}(t) \end{pmatrix} \tag{3}$$

where $Pr_i(t)$ is the probabilities of the transition of the managed object into certain state i, A is the transition matrix containing parameters of the intensity of actions to restore d_i and actions to implement the risk of the corresponding vertex l_i in the state graph. Matrix A is constructed based on the adjacency matrix of the states graph (Fig. 2).

Thus, it is possible to compose the differential equations system describing the effect on the root vertex for the cause-effect graph. The system of differential equations in the case of the 5-element minimal cut sets takes the form.

$$\begin{aligned}\frac{\mathrm{d}Pr_0(t)}{\mathrm{d}t} &= (-l_1 - l_2 - l_3 - l_4 - l_5)Pr_0(t) + d_1 Pr_1(t) + d_2 Pr_2(t) \\ &\quad + d_3 Pr_3(t) + d_4 Pr_4(t) + d_5 Pr_5(t)\end{aligned} \tag{4}$$

$$\begin{aligned}\frac{\mathrm{d}Pr_1(t)}{\mathrm{d}t} &= l_1 Pr_0(t) + (-d_1 - d_2 - d_3 - d_4 - d_5)Pr_1(t) + d_2 Pr_6(t) \\ &\quad + d_3 Pr_7(t) + d_4 Pr_8(t) + d_5 Pr_9(t)\end{aligned} \tag{5}$$

$$\begin{aligned}\frac{\mathrm{d}Pr_2(t)}{\mathrm{d}t} &= l_2 Pr_0(t) + d_3 Pr_{10}(t) + d_4 Pr_{11}(t) + d_5 Pr_{12}(t) \\ &\quad + (-d_2 - l_1 - l_3 - l_4 - l_5)Pr_2(t) + d_1 Pr_6(t)\end{aligned} \tag{6}$$

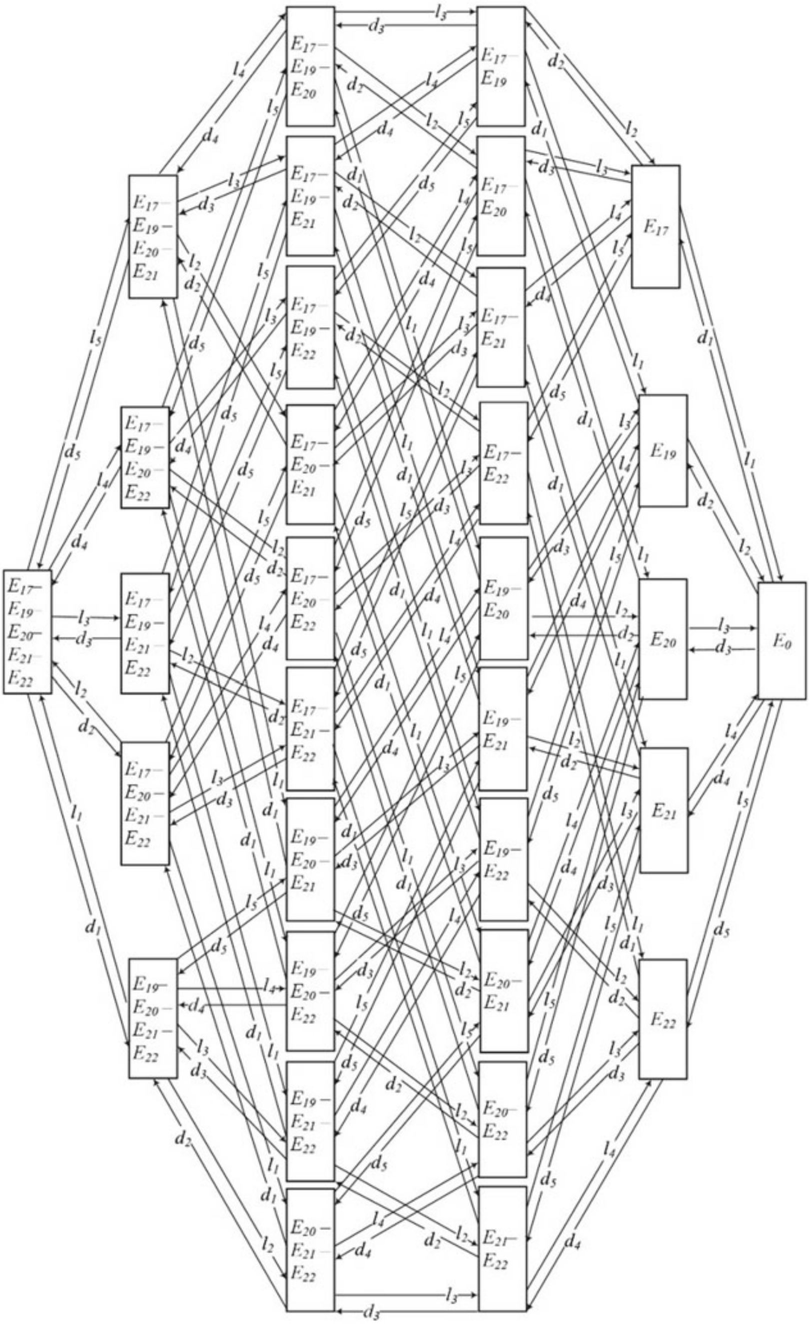

Fig. 2 State graph for a 5-element minimal cut set E_{17}—E_{19}—E_{20}—E_{21}—E_{22}

...

$$\frac{dPr_{31}(t)}{dt} = l_5 Pr_{26}(t) + l_4 Pr_{27}(t) + l_3 Pr_{28}(t) + l_2 Pr_{29}(t) + l_1 Pr_{30}(t) + (-d_1 - d_2 - d_3 - d_4 - d_5) Pr_{31}(t) \quad (35)$$

A solution of system (4)–(35) is carried out by the Runge-Kutta methods.

5 Conducting a Computational Experiment for Specific Regions Based on a Digital Model for Assessing Regional Competitiveness

The proposed approach was being tested on the example of several regions of the Volga Federal district. The research information and analytical database were developed. It used data from open sources [22, 23]. The values of leaf vertices of the cause-effect graph are determined for 2018. The analysis of competitiveness is carried out for the following regions of the Volga Federal district: Saratov region, Samara region, Ulyanovsk region, Republic of Tatarstan. These regions represent objects that differ significantly in terms of socio-economic development. They are indicative of the fact that, given the relative similarity of natural resource conditions, they belong to different categories in the ratings of the socio-economic status of the Russian Federation's subjects [24, 25].

A computational experiment was carried out for the same probabilities of risk development and managerial impact $l_1 = 0.04$; $l_2 = 0.4$; $l_3 = 0.3$; $l_4 = 0.4$; $l_5 = 0.5$; $d_1 = 0.3$; $d_2 = 0.4$; $d_3 = 0.5$; $d_4 = 0.5$; $d_5 = 0.5$. Preliminary calculations were performed to visualize the possible dynamic modes of the model (4)–(35). The obtained calculation results are presented in Figs. 3 and 4.

Initially, the low risk of losing the region's competitiveness at given parameter increases, passes the peak of the maximum value, decreases, and begins to grow again.

The results of a computational experiment (Fig. 3) with fixed values of the model parameters corresponding to the situation with a high level of crisis impacts and an intensive control action response to prevent crisis phenomena at the regional level, allows us to draw the following conclusions. The considered critical combinations of events in the case of deterioration in indicators of innovative and informational risk factors of development and increasing unemployment lead to the fact that the probability of a region's competitiveness decrease does not exceed 0.3 for all these regions. It should be noted that the risk for the leading region, to which the Republic of Tatarstan can be attributed based on existing ratings, is significantly lower and does not exceed 0.15. This is consistent with the widespread opinion of the expert community that leading regions retain their positions in the medium term.

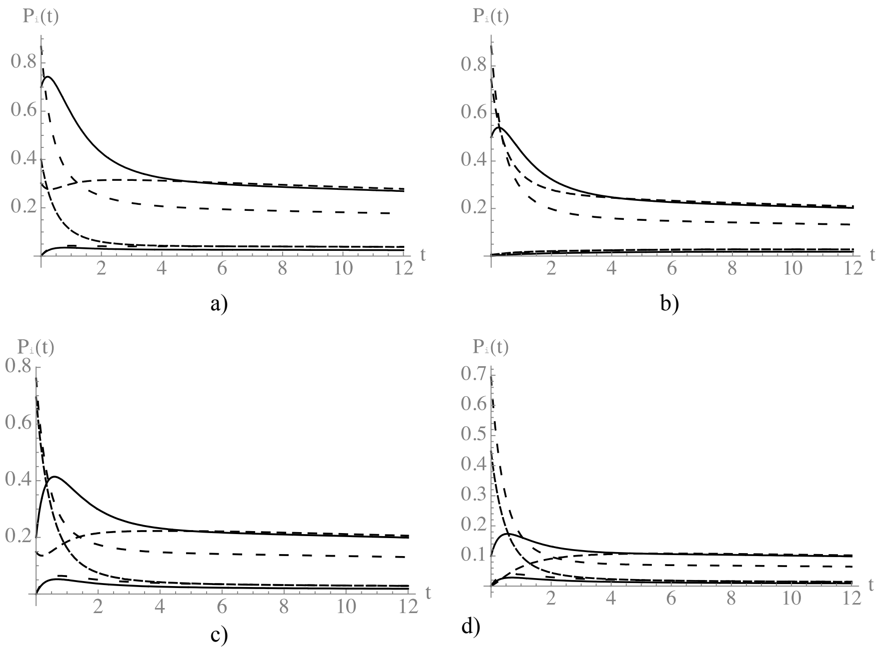

Fig. 3 The modeling results of analyzing the region's competitiveness for Volga Federal district: **a** Saratov region; **b** Samara region; **c** Ulyanovsk region; **e** The Republic of Tatarstan

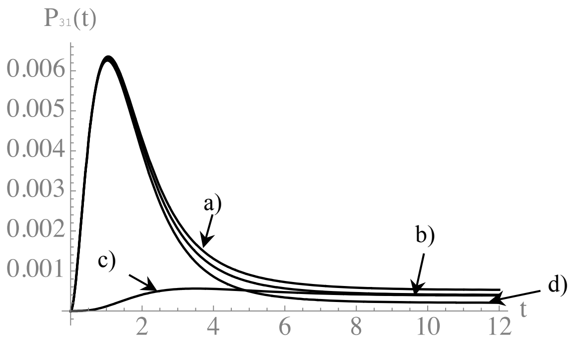

Fig. 4 The probabilities of joint critical realization of events: E_{17}—the number of unemployed, E_{19}—digitalization and using of the Internet, E_{20}—using the Internet electronic documentary exchange in organizations, E_{21}—R & D personnel, E_{22}—sales of innovative goods and services for the regions **a** Saratov region, **b** Ulyanovsk region, **c** Samara region, **d** the Republic of Tatarstan. The model uses the same values of the implementation of the risks and the control actions in the selected minimal cut set

In fig. Figure 4 shows the probabilities of a critical combination of events E_{17}—E_{19}—E_{20}—E_{21}—E_{22} for four different regions: Saratov Region, Ulyanovsk Region, Samara Region, Republic of Tatarstan. The probability values of the risk realization and the occurrence of process stopping due to a critical combination of the events in question, while they do not individually cause a certain risk to be initialized. In general, the simulation results correspond to the expected values, which confirms the adequacy of the model used.

The disadvantages of this approach include the need to neglect a large number of potentially significant indicators of vertices to reduce the size of the model. In the proposed scheme for constructing state graphs for minimal cut sets, this problem is insurmountable. However, due to the significant complexity of the structure of the considering indicators, digital modeling of the region's competitiveness based on the Kolmogorov-Chapman equations is an acceptable way for analyzing a multi-factor socio-economic system.

6 Conclusions

The competitiveness of the region has a dynamic nature and is formed in an evolutionary way depending on the influence of various direct and indirect factors. The dynamics of technical and technological changes, the development of management methods and systems, the change in the needs structure lead to a continuous increase in the number of factors that should be taken into account in the analysis of regional competitiveness. The competitiveness of the region is associated with the multifactorial concept of competitive potential, which characterized the possibility of successful participation in inter-regional and interethnic competitive relations. It assumes the presence and realization of the competitive potential of the regional system. In turn, the assessment of potential in the framework of competitive analysis involves the assessment of risks inherent in a given region. The formation of a hierarchical structure of indicators for risk assessment, as the initial stage of the study, allows the use of mathematical models based on the Kolmogorov-Chapman equations for analyzing the dynamics of the risks of regional competitiveness.

An important aspect of regional competitiveness researching is the analysis and forecasting of potential losses, the assessment of various risk types, and the identification of priority regional policy directions. The applicability of the methods based on the principles of building cyber-physical systems, using the Kolmogorov-Chapman equations to analyze the dynamics of regional development for assessing competitiveness risks is shown. For many strategies developed at the national level, the goal of competitiveness is to develop and maintain measures that encourage wealth (for example, low inflation, an effective institutional environment, open markets, etc.). At the level of subnational territories, the task is to determine priorities within the framework of the strategic plan in conditions of limited resources that have the most significant positive effect taking into account regional conditions.

Using modern digital mathematical models to assess such complex socio-economic objects as the regions by competitiveness analysis will allow us to obtain a more objective characterization. A feature of this study, in contrast to traditional approaches, is the study of digital models that provide assessing regional competitiveness in dynamics when implemented as a cyber-physical system.

Acknowledgements This research was partially supported by the Russian Fund of Basic Research (grant No. 20-010-00465).

References

1. Henderson, H.: Worldwide support found for measuring true wealth of nations. Foresight **10**, 67–69 (2008)
2. Porter, M.: The economic performance of regions. Reg. Stud. **37**, 549–578 (2008)
3. The Global Competitiveness Report 2019, http://www3.weforum.org/docs/WEF_TheGlobalCompetitivenessReport2019.pdf. Last accessed 04.26.2020
4. Annoni, P., Dijkstra, L.: Measuring and monitoring regional competitiveness in the European Union. In: Huggins, R., Thompson, P. (eds.) Handbook of Regions and Competitiveness, Contemporary Theories and Perspectives on Economic Development, pp. 49–79. Edward Elgar Publishing Limited, London (2017)
5. SolAbility. The Sustainable Competitiveness Report (2019). SolAbility Sustainable Intelligence, Zurich, Seoul (2019)
6. Delgado, M., Ketels, C.H., Porter, M., Stern, S.: The Determinants of National Competitiveness, No. 18249, 47 p. NBER Working Paper, Cambridge (2012)
7. Ketels, C.H.: Recent research on competitiveness and clusters: what are the implications for regional policy? Camb. J. Reg. Econ. Soc. **6**(2), 269–284 (2013). https://doi.org/10.1093/cjres/rst008
8. World Economic Forum. Assessing the Sustainable Competitiveness of Nations. In: The Global Competitiveness Report 2013–2014, pp. 53–82. World Economic Forum, Geneva (2013)
9. Enright, M.J.: Why clusters are the way to win the game? World Link **5**, 24–25 (1992)
10. Hausmann, R., Hidalgo, C.A., Bustos, S., Coscia, M., Chung, S., Jimenez, J., Simoes, A., Yıldırım, M.A.: The Atlas of Economic Complexity. MIT Press, Boston (2013)
11. Martin, R.L.: Regional competitiveness: from endowments to externalities to evolution. In: Cooke, P., Asheim, B., Boschma, R., Martin, R., Schwartz, D., Tödtling, F. (eds.) Handbook of Regional Innovation and Growth, pp. 234–245. Routledge, London (2011)
12. Huggins, R., Izushi, H., Thompson, P.: Regional competitiveness: theories and methodologies for empirical analysis. J. CENTRUM Cathedra Bus. Econ. Res. J. **6**(2), 155–172 (2013)
13. Nezhivenko, E., Golovikhin, S., Dubynina, T., Dolinskaia, A.: Regional index of competitiveness of Russian regions. Innov. Manag. Educ. Excellence Vis. **2020**, 4921–4932 (2018)
14. Lomov, E.E.: The competitiveness of the region: elements, indicators, evaluation mechanisms. News of Higher Educational Institutions. Volga Region. Economic Sciences. 1, 105 (2015)
15. Mazilkina, E.I., Panichkina, G.G.: Fundamentals of competitiveness management. Moscow: Omega-L, 328 p. (2008)
16. Stimson, R., Stough, R., Roberts, B.: Regional Economic Development: Analysis and Planning Strategy, 398 p. Springer Science & Business Media (2013)
17. Ketels, C.: Recent research on competitiveness and clusters: what are the implications for regional policy? Camb. J. Reg. Econ. Soc. **6**(2), 269–284 (2013)
18. Inshakov, O.V.: "The core of development" in the context of the new theory of factors of production. Econ. Mod. Russian **1**, 11–25 (2003)

19. Klyuyev, V.V., Rezchikov, A.F., Bogomolov, A.S., Filimonyuk, LYu.: Interaction of resources of complex man-machine systems in critical situation. Control Diagn. **4**, 41–45 (2013)
20. Bolshakov, A.A., Veshneva, I.V., Kushnikov, V.A.: Mathematical modeling of the dynamics of the behavior of social groups to prevent dangerous combinations of events in critical periods of the development of the state. In: Actual Problems of Applied Mathematics, Computer Science and Mechanics: Sat. Proceedings of the International Scientific and Technical Conference, pp. 592–599. Publishing House "Scientific Research Publications", Voronezh (2017)
21. Rezchikov, A.F., Bogomolov, A.S., Ivashchenko, V.A., Filimonyuk, LYu.: Approach to ensuring and maintaining the security of complex systems based on automatic models. Control Large Syst. **54**, 179–194 (2015)
22. Russian Statistical Yearbook 2019: Stat. Book, 708 p. Rosstat, Moscow (2019)
23. Regions of Russia. Socio-economic indicators. https://gks.ru/bgd/regl/b19_14p/Main.htm. Last accessed 04.24.2020
24. Rating of the socio-economic situation of the constituent entities of the Russian Federation: results of 2018. http://vid1.rian.ru/ig/ratings/rating_regions_2019.pdf. Last accessed 05/04/2020
25. Skobelev, P.: Towards autonomous AI systems for resource management: applications in industry and lessons learned. In: Proceedings of the XVI International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS 2018). vol. 10978, pp. 12–25, Springer (2018)