Solution for information and analytical support of staffing management in the Arctic zone of the Russian Federation

Andrey Grigorevich Oleynik*, Vitaliy Viktorovich Bystrov, Darya Nikolaevna Khaliullina

Institute for Informatics and Mathematical Modelling of Technological Processes of the Kola Science Center Russian Academy of Sciences, Fersman st.24a, Apatity, Murmansk region, Russia

Abstract

One of the main problems of Arctic zone development in the Russian Federation (AZRF) is a limited labor resources. Poly-model complex for analysis and simulation of the AZRF labor market is presented in the article. The complex allows you to forecast the formation of the labor demand of socio-economic systems in AZRF and to explore the possibilities of regional professional education systems in terms of meeting the forecasted needs. Technologies of system-dynamic and agent-based modeling are shared within the framework of the complex. The advantage of the presented software tool is the ability to operatively vary not only the quantitative characteristics of the modeled system, but also the structure of interaction between the components of the system. This is a useful opportunity to analyze the possible impact on the regional labor market of investment projects that are planned for implementation in the region. Developed tool was used to support the personnel policy management in the Murmansk region.

Key words: Arctic zone, labor resources management, information and analytical support, simulation, poly-model complex

DOI: 10.5817/CPR2017-2-19

Introduction

Effective performance of the approved strategy of The Russian Federation Arctic zone (AZRF) development [4] is not possible without adequate staffing. The existing problems of staffing in AZRF are largely due to the peculiarities of this territory (adverse climatic conditions, specific socio-economic factors and others). This fact de-

---

Received May 16, 2017, *accepted* November 7, 2017.
*Corresponding author: A. G. Oleynik <oleynik@iimm.ru>
Acknowledgements: The authors thank the Russian Foundation for Basic Research for the support in the frame of the projects №15-29-06973 - *Development of methodology, model toolkit and information technologies for system risk assessment of new exploration of the Arctic region*, № 15-07-04290 - *Development of cognitive methods and technologies for information monitoring of the regional security threats life-cycle (by the example of Arctic zone of the Russian Federation)* and № 16-29-12878 - *Development of methods for identification of dynamic models with random parameters and their application to predict migration in Eurasia*. We would also like to thank the Government of the Murmansk region for the data and advice provided.

termines the lack of attractiveness to live in AZRF and, as a consequence, causes predominance of emigration over immigration of labor resources. Most of the young people, who leave AZRF to obtain higher education in other regions, do not come back. To solve the problems of personnel supply in AZRF, it is very important task to develop and improve professional education systems in such regions. Considering limitation of human and educational resources in the AZRF, it is necessary to focus special attention to the system of professional education. This system has to provide target training of qualified personnel that is required in regional labor market (Fig. 1).

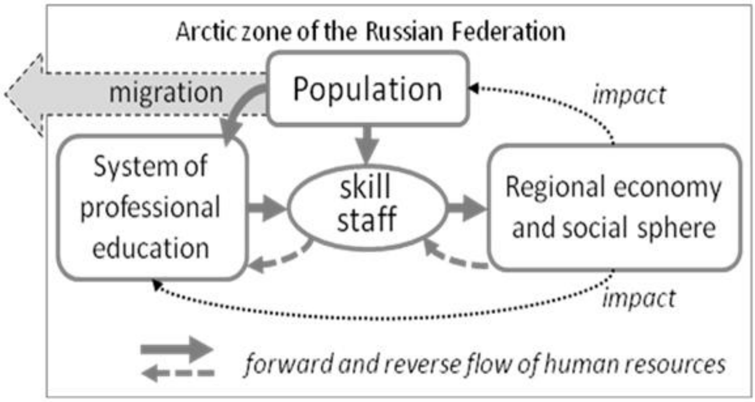


Fig. 1. A simplified scheme of components interaction to solve the tasks of AZRF staffing.

The system of professional education is quite inertial. Therefore, perspective forecasting (up to 7-10 years) of labor market needs is very important. Analysis of possible variants to satisfy predicted labor market needs with using educational resources available in the region is also an urgent task. Extrapolation of existing trends to form adequate forecast is not possible because conditions of AZRF development are changed. Forecasting tools must provide the possibility of conditions and parameters on-line variation. This is necessary to analyze different variants of social and economic processes development and possibility to provide the staffing needs determined by these processes. The program complex which satisfies such requirements was developed in IIMM KSC RAS.

Material and Methods

The program complex combines standard instruments, which process different types of data, and original software tools to form and to study computer models. The models simulate dynamics of processes that determine the supply and demand in the labor market. These models are the main tool to forecast development of regional systems and labor market dynamics in AZRF.

To forecast there are used such basic data as:

• Data from the Regional Employment Center. It is used to determine amount of vacancies in the regional labor market, indicators of dynamics of employment and release of workplaces in the context of positions/specialties/professions and economy branches.

• Results of questionnaire of employers. These results allow obtaining estimates of the number and structure of the required labor needs for the forecast period.

• Results of activity monitoring of professional education institutions. It is the information that characterizes the current and future appearance of new skilled workers on the regional labor market. Also monitoring data allow estimating of the regional education resources potential.

• Data of state statistics authorities. These data allow to estimate changes of staffing in enterprises and organizations of the region.

Methods and tools of system dynamics and agent-based modeling were used together to create simulation models.

The system dynamics (SD) was suggested by Jay W. Forrester as an approach to understanding the nonlinear behavior of complex systems over time using limited set of model's elements: stocks, flows, internal feedback loops, table functions and time delays. SD finds wide application as a simulation tool in various subject areas due to creation of convenient graphical user interface at the 1990s [5]. The system dynamics as a tool to support the professional solution of organizational problems and to study complex processes in various fields is presented in detail in the book of John D. Sterman (Sterman 2000).

The current state and the latest worldwide developments in the SD are presented on the System Dynamic Society web pages [2] and in the journal The System Dynamics Review [3] that is published by the Society.

The system dynamics has proven itself as a good tool for finding the answer to the question «what will be if ...?» in complex systems. Therefore SD was selected by the authors as the basis to create simulation tool for forecasting in staffing management problems of AZRF.

Agent-based modeling (ABM) was used because formation of supply and demand for labor is a result of the interaction of many stakeholders in the regional system. In ABM, a system is modeled as a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules. Agents may execute various behaviors appropriate for the system they represent (Bonabeau 2002).

AnyLogic was selected as the development environment that allows to construct and share both system-dynamic and agent-based models. This software was developed by the Russian company The AnyLogic Company [1]. The tool has a modern graphical interface and allows you to use the Java language for model development (Karpov 2006).

The original technologies developed in IIMM KSC RAS were applied for creation of the simulation models synthesis block (Putilov et al. 2003, Bystrov et Kodema 2006, Putilov et al. 2008, Oleynik et Leksikov 2008, Gorokhov et Shelekh 2009, Gorokhov et al. 2013, Khaliullina 2016):

1. An information technology to form applied simulation models on the basis of a limited set of "mobile" patterns (Oleynik et Leksikov 2008). Its practical realization consists of the following steps:

a. Analysis of the subject area to identify a limited set of typical processes that determine dynamics of the considered system development.

b. Creating SD pattern for each typical process.

c. Forming of “Mobile” patterns library for applied modeling environment to synthesize on the basis of SD patterns.

d. Constructing simulation model for analysis of complex process by linking of library's patterns. Every pattern represents some subprocesses of the analyzed process.

e. Putting parameters and initial data into the model and carrying out series of simulation experiments to study analyzed process development variants.

f. Make the decision on the basis of simulation results analysis.

Fig. 2 presents a simplified example where the model of 3-year educational program is formed by consecutive connection of three same patterns. These patterns describe the structure of the 1-year learning process.

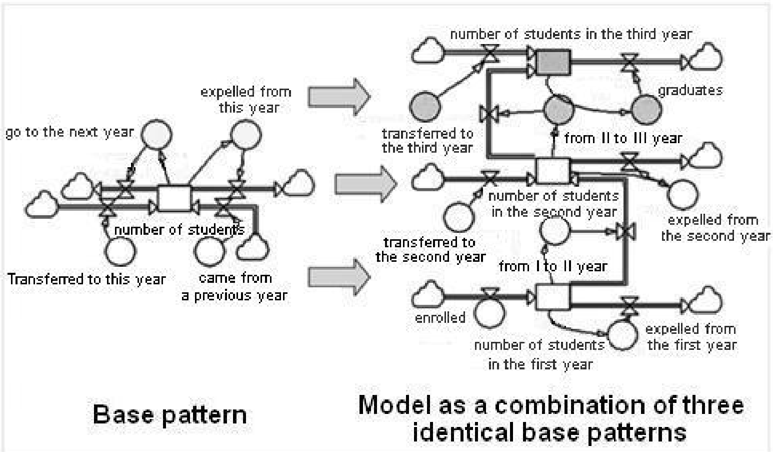


Fig. 2. Example of model synthesis by using of basic pattern.

2. The technology of automated synthesis of SD model structure based on the cognitive map (Khaliullina 2016). Synthesis is provided by realization of the following steps:

a. Forming the initial cognitive map (ICM).

b. Mapping ICM nodes to stocks of SD model.

c. “Breaking” of ICM relations by adding new nodes and mapping arcs to on flows in SD model.

d. To refine ICM by adding new nodes and arcs and by mapping those to variables and constants in SD model.

e. Analysing of the SD model and transformation of SD model stocks to variables if it is necessary.

The synthesis is performed in accordance with the mapping rules (Table 1). Using computer-aided procedures, SD model is being built for work in the AnyLogic system.

Cognitive map is defined formally as a tuple $KognM = < G, F >$ (Gorelova et al. 2005) where:

1) $G = < V, E >$, $V = \{v_i \mid v_i \in V, i = 1,2,\ldots,M\}$, $E = \{e_i \mid e_i \in E, i = 1,2,\ldots,P\}$, where

G – directed graph, V – node set of the graph («concepts»), E – set of arcs, M - number of nodes, P - number of arcs.

2) $F = F(V,E) = F(v_i, v_j, e_{ij})$, where

F – functionality of arcs transformation. F puts in correspondence to each arc the sign ("+","–"), indicating «positive» or «negative» impact of the concept v_i on a concept v_j.

$$F(V,E) = \begin{cases} +1, \text{ if } \textit{increasing (decreasing)} \text{ value } v_i \\ \quad \text{influences } \textit{increasing (decreasing)} \text{ value } v_j \\ -1, \text{ if } \textit{increasing (decreasing)} \text{ value } v_i \\ \quad \text{influences } \textit{decreasing (increasing)} \text{ value } v_j \end{cases}, \quad i, j = 1,2,\ldots,M; i \neq j$$

In AnyLogic program, the elements of SD model are represented by the following collection of sets:

$SDM = \{S, Fl, Var, C, R\}$, where S – set of stocks; Fl – set of flows, that reflects the rate of stocks change, their filling and reduction; Var – set of variables; C – set of constants; R – set of information links.

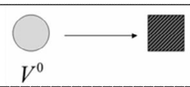
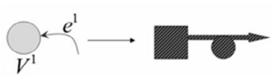
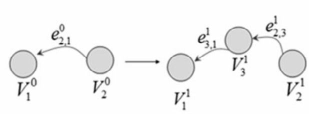
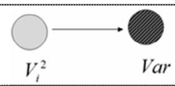
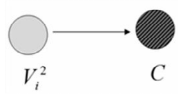
The mapping rule	Graphical representation
$V^0 \to S$	
If $F(V^1_{i,j}, e^1_{(i,j),j}) = +1$ then $(V^1_{i,j}, e^1_{(i,j),j}) \to Fl_i^+$	
If $F(e^1_{i,(i,j)}, V^1_{i,j}) = -1$ then $(e^1_{i,(i,j)}, V^1_{i,j}) \to Fl_i^-$	
$e^0_{i,j} \to V^1_{i,j}, e^1_{i,(i,j)}, e^1_{(i,j),j}$	
$V_i^2 \to Var$	
$V_i^2 \to C$	

Table 1. Matching the mapping rules to their graphical representation.

The technologies of SD models synthesis on the basis of “mobile” patterns and cognitive maps were used in developing of complex of simulation models to solve staffing needs tasks. The complex includes four main modeling blocks:

1. «Demography». This block simulates the demographic processes that take place in the region. It can be presented formally as a tuple:
D = <P, BR, DR, Im, Em>, where P – population; BR – birth rate; DR – death rate; Im – immigration; Em – emigration.

2. «Regional Labor Market». This block is designed to assess and search for the balance between supply and demand for labor. The block is described by a tuple:
LM = <Dem, Sup>, where Dem – demand; Sup – supply.

3. «Regional Economy». This block simulates the main processes taking place in basic sectors of the regional economy from the point of view of their staffing. Also it takes into account ongoing and planned investment projects. Regional economy is presented by a set, each its element characterizes some economy branch:

$RE = \{EB_j\}$, j=1,..,K, where
$EB_j = <Ent_j, Vac_j, WP_j, Res_j, IP_j>$ - economy branch;
Ent_j – enterprises of j-th economy branch; Vac_j - vacancies of j-th economy branch;
WP_j – work places of j-th economy branch; Res_j – resources of j-th economy branch.
$IP_j = \{IP_{ji}\}$, i=1,..N_j - investment projects of the economy branch;
$IP_{ji} = <R_{ji}, LC_{ji}, Per_{ji}>$ - specific investment project;
R_{ji} – resources of the investment project; LC_{ji} – life cycle of the investment project;
Per_{ji} – deadline of the investment project.

4. «Professional Education System». This block includes all levels of professional education and is described by the following tuple:
Ed = <HE,SPE,OR,AE>, where HE – higher education; SPE – secondary professional education; OR – occupational retraining; AE – additional education.

Each component of the poly-model complex is implemented as an agent model which can have a multilevel structure. At each level, a combination of both agent-based (AB) and SD models can be used.

SD model that describes demographic processes uses specific parameters, variables and coefficients. Parameters and variables characterize the age and sex structure of the population, the working-age population, rates of death, birth, migration. Coefficients determine the degree of influence of different factors on main demographic parameters. This model allows you to obtain forecasts of the number of economically active populations in terms of age groups and the number of people who can go to regional system of professional education and retraining.

The model of professional education system has a complicated structure because it represents a set of AB models. Each of AB models simulates training of qualified personnel of appropriate level and type of education: bachelor's degree, master's program, specialty, vocational training of mid-level specialists (VTMLS), training of skilled workers and employees (TSWE). In this case, each AB model responsible for the specific type and level of education contains models of educational programs. Such program represents individual model agent that was built by the methods of system dynamics. Data sets about prepared qualified personnel are formed at the output of the AB models. Data are divided into sets by consolidated training groups and by individual educational programs.

Block «Regional Economy» simulates enterprises activities in basic economy branches of the region. To determine labor needs on enterprises and organizations of the region, dynamics of main economic indicators of their activities are considered. Each economic object that is represented in this block is implemented in the form of AB model. In accordance with the context of the tasks these agents can create nested structures. For example, agents are the mining industry as a whole, and specific enterprises of this industry.

Block «Regional Labor Market» generates indicators of supply and demand for labor resources on the basis of data that are results of other blocks work («Professional education system», «Regional Economy» and «Demography»).

Demand for personnel depends on the required number of workers with certain professions and positions. This fact is caused by the process of natural retirement of employees, the appearance of new work places due to implementation of investment projects, the modernization of organizational structure and technology of production. Supply of labor resources directly depends on the number of unemployed people in the region. In the model, the main sources of unemployment people are considered: reduced or dismissed people, graduates of schools and institutions of vocational education, labor migrants who have newly arrived to the region.

Relations between the listed blocks can be represented in a conceptual schema of poly-model complex (Fig. 3).

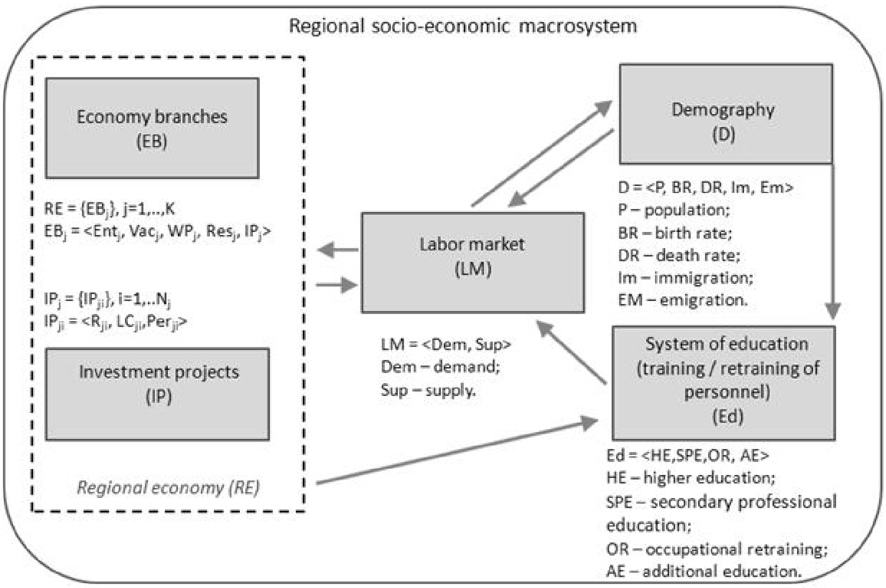


Fig. 3. A conceptual schema of the poly-model complex.

For example, the model «Stage of investment project implementation» is presented (Fig. 4). This agent represents a pattern of SD model that consists of four stocks, nine flows, seven variables and five parameters.

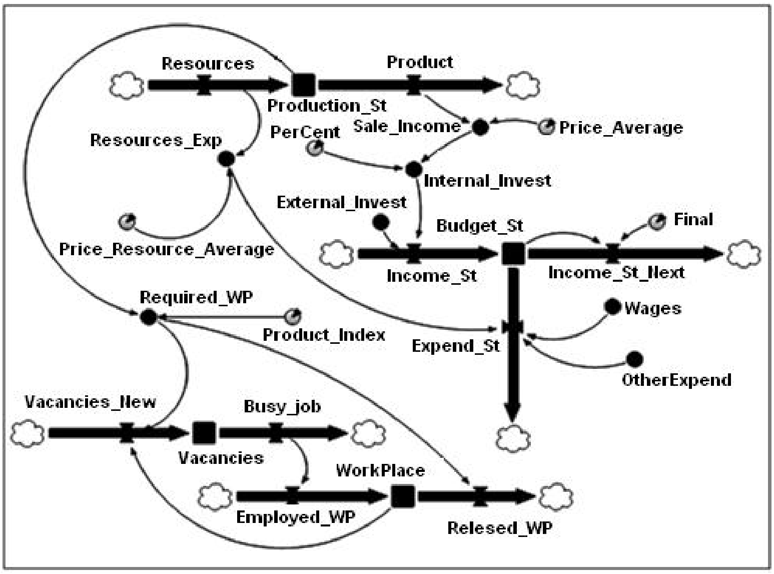


Fig. 4. Pattern of stage of investment project implementation.

The development of any investment project goes through several stages from initialization to completion. Each stage can be described in terms of three main components: financial, resource and time. Time component is a period of investment project life on specific stage of implementation. Financial component reflects financial flows received and spent. Resources of investment project are material and technical base and staffing.

This pattern of SD models can be mathematically represented as a system of differential equations:

- Investment project budget of a particular stage:

$$\frac{dBSt(t)}{dt} = IncSt(ExtInv(t), IntInv(t), t) - IncStN(BSt(t), Fin(t), t) -$$
$$- ExpSt(Wag(t), OtExp(t), ResExp(t), t)$$

- Volume of production (services) in the implementation of the investment project stage:

$$\frac{dPrSt(t)}{dt} = Res(t) - Prod(t)$$

- Number of vacancies of investment project stage:

$$\frac{dVac(t)}{dt} = VacN(ReqWP(t), WP(t), t) - Bj(t)$$

- Number of work places of investment project stage:

$$\frac{dWP(t)}{dt} = EmpWP(Bj(t),t) - RelWP(ReqWP(t),t).$$

This agent is one example of elementary block implementation. Total simulation model is gathered from such elementary blocks in accordance with parameters of a solved task.

Results

Developed poly-model complex was used to solve a number of tasks related to the personnel policy management in the Murmansk region. One of such task was to forecast additional staffing needs (ASN) of organizations and enterprises of the region for the period up to 2025. The notion of additional staffing needs reflects the number of workers that are required in planning period in addition to the existing number of workers at the beginning of the period. ASN arise from leaving workers for various reasons, and from creation of new work places caused by launch of new production facilities or expansion of existing enterprises, including as a result of implementation of investment projects.

To assess ASN of the Murmansk region for the period from 2016 to 2025, a series of computational experiments were conducted. Input information for simulation models was retrospective data of the state statistics (macroeconomic indicators of the regional economy), results of monitoring of labor market from the Regional Employment Center and results of questionnaire of employers.

Computational experiments allowed us to obtain forecasts about the number of employees, additional staffing needs, and the number of graduates of professional educational institutions. Table 2 presents a comparison of graduates who are required in the region and those who can be graduated from regional education and retraining system in the context of education level.

It was established that in the Murmansk region, the ASN for most types of economic activities reduced. This is typical for the «inertial» scenario of development.

Number of graduates	Level	2016	2020	2025
Required	Bachelor	918	917	1028
Can be train in the MR		550	565	677
Required	Master's degree	290	284	281
Can be train in the MR		111	108	111
Required	Specialist/ engineer	1791	1797	1832
Can be train in the MR		152	132	132
Required	VTMLS	2754	2523	2410
Can be train in the MR		1391	1208	1089
Required	TSWE	1880	1663	1519
Can be train in the MR		1359	1203	1112

Table 2. Supply and demand for graduates in the Murmansk region.

Discussion

The conducted researches have shown that the developed complex of predictive modeling reproduces the results obtained by using the current method of forecasting staffing needs. The advantage of the forecasting tool created by the authors is the ability to operatively vary not only the quantitative characteristics of the scenario, but also the structure of interaction between the components of the system, and the factors that influence the development of the situation. This allows us to analyze possible variants of development more completely, include consideration of new factors and exclude irrelevant impacts. As a result, the capabilities of decision makers to search for and justify the most effective solutions of emerging problems, expands significantly.

For example, the task of searching and comparative analysis of solutions for problems of meeting the additional staffing needs in the Murmansk region can be considered. Table 2 shows the results of forecasting of ASN in the region for the period to 2025. These results are aggregated by educational levels for required qualified workers. Obtained data show that there is a growing of demand for workers with higher education. It should be noted that current professional educational system in the region cannot satisfy additional staffing needs at none of the levels of training. Taking into consideration strategic plans to intensify economic activity in the Russian Arctic, the situation with engineering personnel is the most difficult.

Taking into account the above features and constraints characteristic for AZRF, the solution should be based on the analysis of combinations of administrative and economic measures. It is essential to determine the conditions of mutually beneficial cooperation between government agencies and business representatives to solve this problem.

The research showed that simulation modeling allows you to quickly assess the possible impact of investment projects on the regional labor market. However, there is a possibility to form a «package» of forecasts calculated for various variants of investment projects development. This fact allows decision makers to plan for staffing in accordance with situation, and make adjustments to plans that are being implemented, in accordance with the predicted changes of conditions, if it is necessary.

References

BONABEAU, E. (2002): Agent-based modeling: methods and techniques for simulating human systems. Proc. National Academy of Sciences, 99 (3): 7280-7287.

BYSTROV, V. V., KODEMA V. A. (2006): Development of information system of automation of synthesis of dynamic models of complex systems. *Informatsionnye tekhnologii v regional'nom razvitii*, Vol.VI: 93-96. (In Russian).

GORELOVA, G. V., ZAKHAROVA, E. N. and GINIS, L. A. (2005): Kognitivnyy analiz i modelirovanie ustoychivogo razvitiya sotsial'no-ekonomicheskikh system [Cognitive analysis and modeling of sustainable development of socio-economic systems]. Publishing house of Rostov University, Rostov-on-don, Russia, 288 p. (In Russian).

GOROKHOV, A. V., SHELEKH, O. V. (2009): Synthesis of simulation models of macro-systems on the basis of ontological descriptions. *Proceedings of the ISA RAS*, 39: 195-201. (In Russian).

GOROKHOV, A. V., VLASOVA, K. I. and IVANOV, K. I. (2013): Synthesis of system-dynamic models of socio-economic systems based on ontological descriptions. Vestnik of Volga State University of Technology. *Economy and management*, 3: 17-23. (In Russian).

KARPOV, YU. G. (2006): Imitatsionnoye modelirovaniye sistem. Vvedeniye v modelirovaniye s AnyLogic 5 [Simulation of systems. Introduction to modeling with AnyLogic 5]. BHV-Petersburg, St. Petersburg, Russia, 400 p. (In Russian).

KHALIULLINA, D. N. (2016): Problem-oriented program complex to support strategic planning of development of small innovative enterprises. *SPIIRAS Proceedings*, 1(44): 190-211. (In Russian).

OLEYNIK, A. G., LEKSIKOV, A. N. (2008): The tools for interactive formation of simulation models of the activity in the regional system of professional education. *Proceedings of the ISA RAS*, 39: 267-276. (In Russian).

PUTILOV, V., OLEYNIK, A. and GOROKHOV, A. (2003): The Conceptual Synthesis Methods of the Dynamics Models for Complex System. The International Industrial Simulation Conference "ISC'2003", Valencia, Spain, June 9-12: 136-140.

PUTILOV, V. V., GOROKHOV, A. V. and BYSTROV, V. V. (2008): The synthesis of simulation models of complex systems based on expert knowledge. *Informatsionnye tekhnologii i vychislitel'nye sistemy*, 2: 27-35. (In Russian).

STERMAN, J. D. (2000): Business Dynamics: Systems Thinking and Modeling for a Complex World. McGraw, New York, USA, 982 p.

Web sources / Other sources

[1] Official site of AnyLogic (2017)
available at: http://www.anylogic.ru. (Accessed 15 May 2017).

[2] Official site of System Dynamics Society (2017)
available at: http://www.systemdynamics.org. (Accessed 15 May 2017).

[3] Official site of System Dynamics Society (2017), "System Dynamics Review", available at: http://www.systemdynamics.org/publications/system-dynamics-review. (Accessed 15 May 2017).

[4] The order of the President of the Russian Federation, 8 February 2013, № PR-232, "The Strategy for the Development of the Arctic Zone of the Russian Federation and the National Security Strategy for the period up to 2020".

[5] RADZICKI, M. J., TAYLOR R. A. (2008): Origin of System Dynamics: Jay W. Forrester and the History of System Dynamics. In: Introduction to System Dynamics U.S. Department of Energy's available at: https://www.systemdynamics.org/DL-IntroSysDyn/start.htm (Accessed 15 May 2017).