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O. V. Prokhorov[1], Cand. Sc. (Tech.), Assoc. Prof.,
V. P. Prokhorov[2], Cand. Sc. (Tech.), Senior Research Fellow ,
A. O. Matiushko[1],
Y. A. Kuznetsova[1], Cand. Sc. (Tech.)

1 – National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine, e-mail: al_val@mail.ru
2 – "Radio electronics and informatics" Science park, Kharkiv, Ukraine

REGIONAL RESOURCES MANAGEMENT BY AGENT-BASED SIMULATION

О. В. Прохоров[1], канд. техн. наук, доц.,
В. П. Прохоров[2], канд. техн. наук, старш. наук. співроб.,
А. О. Матюшко[1],
Ю. А. Кузнецова[1], канд. техн. наук

1 – Національний аерокосмічний університет ім. М. Є. Жуковського „ХАІ", м. Харків, Україна, e-mail: al_val@mail.ru
2 – Науковий парк „Радіоелектроніка та інформатика", м. Харків, Україна

УПРАВЛІННЯ РЕГІОНАЛЬНИМИ РЕСУРСАМИ НА ОСНОВІ АГЕНТНОГО ІМІТАЦІЙНОГО МОДЕЛЮВАННЯ

Purpose. Efficiency of regional resource management improvement based on self-organization and adaptation in multi-agent systems in conditions of uncertainty and dynamic environment.

Methodology. The given research studies are based on using system analysis methods in order to choose the directions of modeling regional management processes; simulation modeling and theory of multi-agent systems for agent simulation model for regional resource management development.

Findings. Analysis of regional development management features and existing approaches and methods of analysis and decision making in this field was carried out. A structure of simulation agent model for regional resource management was designed.

Originality. Simulation agent model for regional resource management was developed, economical self-organization and collective adaptation of model elements with their own interests and decision making process were implemented, which allows flexible decentralized resource management planning in conditions of a dynamic environment.

Practical value. The designed model represents methodological basis for creating management decision making tools, which provides development planning and effective regional resource usage.

Keywords: *region, resources, resource potential, agent model, regional development*

Introduction. In the context of the local government reform and territorial organization of power in Ukraine, including the empowerment of local communities (cities, villages), budget decentralization, and the system of public services (administrative, social and communal), the issues related to the development of effective forms and tools of regulating sustainable development processes and management of regional social and economic potential in terms of all its components, acquire special urgency. The variety, specificity and complexity of resource support for regional development, as well as the significant impact of the progress and dynamics of resource usage on the efficiency of functioning of the production and economic system of the region as a whole, determine the need for an integrated system approach to solving the problem of the administrative regulation of the resource formation and usage process.

Ineffective management and misuse of funds, property and other local resources makes the task of local and regional development urgent in the context of regional policy, budgetary, fiscal and municipal reforms through decentralization of power, consolidation of resource procuring and strategic planning of developing local communities.

Analysis of the recent research and publications. The conducted analysis of the object of study allowed identifying the main features of the region:

- uniqueness – each region differs from other regions in the set of natural, historical, economic, and national peculiarities;
- dimensionality associated with the presence of a large number of elements with local objectives;
- hierarchical multilevel and multi-loop control;
- multi-aspect views and multi-purpose nature of the functioning;
- dynamic and probabilistic nature of functioning;
- emergence, i. e. the presence of integrative properties inherent in the system as a whole, but not peculiar to any of the individual elements.

Thus, the region belongs to a class of complex socio-economic systems, with a high degree of integration that has a number of features which influence the selection and substantiation of methods of their study.

Among the analysis techniques regarding management and decision-making processes in the field of regional development, a balance method and an equi-

librium model, probabilistic and statistical methods, simulation, methods of intelligent information technology, etc. can be distinguished.

The balance method of planning is based on the mutual alignment of resources, which a region will have, and the need for them within the planning period. It should be noted that the balance method only produces the final results based on specified parameters, but it does not capture their dependence on the initial data, does not set criteria for choosing the best option and does not provide specific recommendations.

The most powerful and promising tools for analyzing complex dynamic flow processes in a large number of variables, in the complexity of the mathematical analysis of dependencies, in a high level of uncertainty of the test situations are simulation tools and methods. Currently three main approaches have been formed and are most widely used: discrete event simulation, system dynamics models and agent-based modeling.

By studying the trajectories of the "movement" of the dynamic model of the system in the space of its internal states, system dynamics models have proven to be an effective approach to the study of macroeconomic systems. In research [1], a complex of simulation models of system dynamics of socio-economic development of the region and the overall structure of the computer system for territorial systems analysis are proposed. However, this type of simulation largely directed at identifying significant variables and setting interconnections between them, does not account for qualitative changes in the system and, therefore, does not allow making an adaptive decision.

The agent approach is the most promising way to increase regional management of resources, taking into account the dynamics and uncertainty. The multiagent system, which is an artificial society, is able to simulate the behavior of the territorial socio-economic system based on the reconstruction of its internal structure, as well as the structure and behavior included in its smaller economic agents. Thus, the agent model is able to demonstrate the dynamics of socio-economic characteristics of the system as a result of the actions (and interactions) of a set of independent agents, taking into account their diversity.

It is more important when it comes to coordinating the use of resources, as it is the top-level task, and most of the processes (monitoring, diagnostics, planning) require intelligent, autonomous, social abilities. The use of agent-based systems for the planning of social and economic development of the regions makes it possible to solve two major problems of scalability and adaptability.

In [2] an agent-based system is considered that simulates the development of the economy (construction of new facilities, improving the overall level of income) on the basis of the territorial model of the system, however, only the issues of forming a set of specializations of each region are described.

Research [3] proposes a conceptual diagram of a system of agent-based models designed to optimize flows of public finance in the state. The main emphasis is made in the direction of formation of the optimal configuration of the administrative units and economic conditions of conducting economic activity.

Much of the research in the field of management of regional development considers problems of planning the territorial location of various objects. The research [4] deals with the agent-based modeling of functioning and spatial distribution of households and firms. The model describes a multi-raw, land and labor markets in the system of municipal management and the behavior of these entities in order to maximize profits and reduce transport costs.

Quite a lot of research studies concern the modeling of the dynamics of land management and land use – land use/cover change (LUCC). The research [5] deals with the modeling and decision-making on land use and the choice of the regional development strategy. However, the emphasis is made in the direction of identifying different types of agents and their parameterization based on empirical research.

Objectives of the article. Analysis of existing methods and the regional management model has shown that an integrated approach is required in the formation of an efficient regional development management system, aimed at the selection of the volume, cost, and time to involve some resources under the relevant parameters of other resources.

For the effective management of regional resources, targeted conceptual management of the process of formation of the region's resource potential is required; its boundary representation is reflected in Fig. 1.

The resource potential of the region will be considered in six components: finance and investment, technology, innovation, market, natural resources and human resource potential.

Financial and investment potential is defined as the capacity and the ability to provide continuous financial circuit of capital, to invest in production and financial assets in order to achieve the strategic goals of the region development.

Technical potential is crucial and includes not only the consideration of the internal environment of the region, but also a certain relationship with the external environment. The technical potential is considered from a perspective of its organizational, technical and technological capabilities, due to the respective production facilities placed in the region.

The innovation potential is proposed as a set of available resources, capacities and capabilities for the use of innovation in the industrial, financial, managerial and marketing activities, as well as participation in the innovation process in order to achieve strategic objectives.

The human resources potential is considered as a set of skills and employment abilities of people living in the region, who are engaged and can be employed in the regional and social production of goods and services.

By the natural resource potential will be meant the ability of all components of natural resources of the region (regarding their status, location, conditions of occurrence and other characteristics) to ensure proper reproduction and restoration, the production of products and services, maintaining proper conditions of the pop-

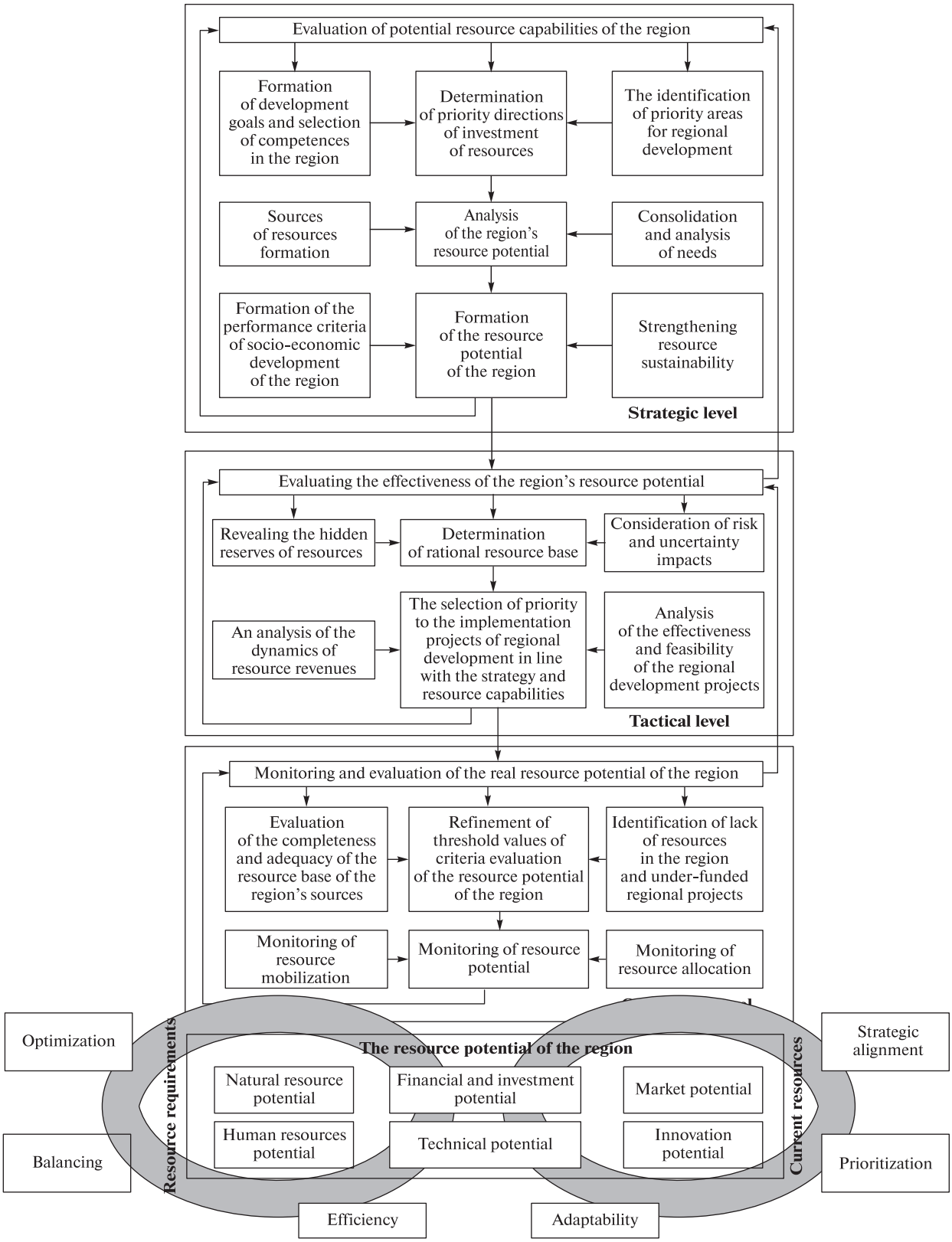

Fig. 1. Multilevel model of the formation and evaluation of the resource potential of the region

ulation. The market potential is to be allocated in the structure of the resource potential of the region as its capacity to produce and sell competitive products, maintaining and/or expanding their market segment. In this context, the market potential is regarded as a category that takes into account the state of and changes in the internal and external environments, as well as establishing their close relationship and interaction. The development of this capacity is a precondition not only to successful functioning, but also to the development of

the region. The strategic level includes the formation of targets of the regional system development considering its prospects. It identifies competencies of the region, the definition of priority directions of development, the formation of the regional development plan, and the determination of the parameters of control actions.

Further on, volumes are determined to implement a set of measures designed, sources and timing of the formation of resource provision. The first involves identifying the volume and sources of financial resources needed to implement the strategy. Based on the results obtained, the projects of socio-economic development of the region in the medium term are generated. Implementation of these projects will lead to a change in the socio-economic situation, the control of which and the identification of shortages in resource maintenance are carried out in the course of monitoring at an operational level.

In case of negative deviations of key performance indicators, the first task is to return rates in the range of permissible values, that is, to bring them to the normative values. This adjustment requires changes at every level.

The main instrument for achieving the objectives of social and economic development of the region is to provide its interaction with the external and internal environments, which allows maintaining and using its potential level. Managing the development of the resource potential of the region in the changing parameters of the external and internal environments reveals the essence of resource exchange and resource use in the context of the process of strategic planning of development of the region and provides the implementation the region's growth strategy.

Implementation of the concept of effective regional management requires the solution of problems related to the structuring of the underlying resource flows, the definition of their characteristics, choice of instruments of influence, the development of mechanisms for responding to changes in the parameters of the internal and external environments.

General principles of formation and regulation of resource flows are: efficiency, i. e. reducing costs and maximizing profits; diversification, i. e. the formation and regulation of resource flows; balance which is aimed at establishing a correspondence between incoming and outgoing flows in order to achieve consistency of resource movement or to the full and effective use.

Resources must be allocated between the different areas of use for individual intervals of the planning period in order to obtain the maximum overall efficiency of the chosen distribution method. However, the main tasks are as follows: optimization, i. e. the allocation of resources to maximize the value of the region's development portfolio; balancing to achieve the desired balance of resources; strategic alignment, i. e. ensuring that a fixed amount of resources in the implementation of development projects will be spent in accordance with the achievement of strategic objectives; prioritizing, i. e. ranging portfolio of projects to achieve the best balance between resource requirements and their availability; adaptability, i. e. the ability to adjust to changing conditions dynamically and flexibly.

The solution of the regional resource management task comes in a diversity of factors affecting the economic development of the region, the dynamic changes in the socio-economic environment, as well as under the contradictory goals of participants of the regional administration development process. Consequently, there is a need to provide a mechanism to search for the optimal, balanced management decisions formed taking into account the characteristics of each region and the dynamics of its socio-economic development.

The conducted analysis of the research in this area has shown that multi-agent systems regarding advantages provided by them (autonomy, decentralization, individual behaviour with the possibility of learning and adapting to their constituent agents) automate the complete regional management cycle, including the harmonization of interests, coordinated interaction, dynamic scheduling and adaptive re-planning resources. The features discussed lead to the fact that the regional management model is to be able to redevelop dynamically through the creation/deletion of elements and connections between them, to supplement or clarify the "on the go", the inclusion of different scenarios of behavior of adaptation mechanisms. In multi-agent systems the behavior is determined at an individual level, while the global behavior arises as a result of many agents, each of which follows its own rules, operating in a shared environment and interacts with the environment and with other agents.

Agent-based simulation model for the analysis of regional resource management processes. According to the changes in the administrative-territorial reform, Ukraine has a three-tier structure of the local government: the region (area) - region (district) - a community (village, town, and city). The territorial socio-economic system is described as

$$TS = \langle Rg, E^{TS}, M^{TS}, R^{TS} \rangle,$$

where Rg is a set of its constituent region-agents, E^{TS} is the environment in which agents operate, M^{TS} is a set of external and inter-regional markets, R^{TS} is a set of time developing relations between agents (shown on the set of inter-regional markets).

The region can be represented as follows

$$Rg = \langle F, H, B, M, R, ORG, P \rangle,$$

where F is a set of enterprise agents, H is a set of household agents, B is a set of budget organization agents, M is a set of internal markets, R is a set of links between agents, ORG is a set of base administrative territorial structures in the region (districts and communities), P is a set of scenarios (policies) of regional development.

The goal of each region is to determine the parameters of the socio-economic system and the adoption of measures to achieve them.

The material and financial basis for the independence of local governments are: movable and immovable property which is in the communal ownership; income of regional (local) budgets; extrabudgetary

funds; other means; the land and other natural resources that are in communal ownership; collaborative property of territorial communities in the management of district and regional councils.

One of the central problems in the agent-based modeling of flow processes in the considered system is the formation of a variety of alternative options to resource attraction and allocation. In this case, the simplest version of multi-agent community organization in dealing with regional resources management tasks can be based on the interaction of attracting agents and placement agents, looking for a matching of the resources available on the market. Competing and cooperating with each other while making "deals" in order to meet emerging problems jointly (for this agents can use the advanced economic instruments, including equity, auctions, etc.), agents can provide new opportunities in the system of self-organization for a permanent adaptation to the changing situation.

Thus, agents, representing regions, consume resources that are provided from the external environment (absorb imported products), and, in turn, generate the mass of commodities, as part of their industry specialization, to the external environment (they export products produced on its territory to external inter-regional markets). Each region may have several sets of possible specializations. As specializations the following issues are considered: agro-industrial development; utilities and infrastructure; culture and tourism; education and science; health protection; pharmaceuticals; information; labor and social protection of the population; physical culture and sport; economy; family and youth; construction and architecture, etc.

In other words, if the agent of the region needs any products from the interregional specialization, he/she "negotiates" with that agent, and commodity-material connection is established between them by means of market interaction.

As the markets, we consider: the labor market; the market of goods and services; the market of natural resources; the intellectual property market and the financial market. Each market is defined as follows

$$M = \langle D, S \rangle,$$

where D is demand, S is offer.

A set of markets has the following structure

$$M^{TS} = M_E \cup M_{NR} \cup M_I,$$

where M_E is set of markets outside the territorial system (country) – the external markets; M_{NR}, namely, a set of inter-regional markets, describing the needs of areas of various types of products, resources, and so on; M_I is a set of internal regional markets, describing the needs that can be met only within the region.

The financial market plays an important role – it provides a redistribution of financial resources between businesses and households through financial and credit mechanism in order to create funds of money resources and loans. Financial resources are made of budget resources of all the levels, which are used for current financing of the regional economy, social sector, investing important projects; extra-budgetary funds resources; object resources that are used for the financing working capital and capital investments, maintenance of own social infrastructure objects; credit resources of commercial banks and other financial institutions; grants, subsidies, subventions and other income from the state budget of Ukraine in order to overcome the deficit of regional budgets and centralized investments.

Thus, the region is described by a complex of enterprise agents, households and budget organizations that interact in markets of goods and services, labor, finance, etc.

The enterprise agent reflects the activity of economic entities functioning in the region. The goal of the agent is the maximization of profits, which does not exclude the implementation of other objectives. Acting as attracting agents, they acquire the necessary resources for the production. Transforming resources into in-progress and finished goods during the production process, the agent plays the role of a producer. Then, delivering the finished product to the sphere of circulation, they become placement agents and can sell products on commodity markets or export them to other regions.

Revenues of the enterprise agent are formed in the context of three types of activities – operational, investment, and financial ones, and include revenues from selling products I_S^E; credits and loans I_L^E; proceeds from issuance of shares I_{ST}^E; special-purpose financing I_{SPF}^E; increase in share capital I_{CC}^E

$$\frac{d}{dt} I^E(t) = I_S^E(t) + I_L^E(t) + I_{ST}^E(t) + I_{SPF}^E(t) + I_{CC}^E(t).$$

The expenditure part is constituted by the gross production costs C_W^E; payments to the budget and extra-budgetary funds C_T^E; payments for credits C_L^E; investments in fixed capital C_{IC}^E; $R\&D$ costs $C_{R\&D}^E$; the formation of the owner income (dividend payment) C_D^E; short-term investments C_{STF}^E

$$\frac{d}{dt} C^E(t) = C_W^E(t) + C_T^E(t) + C_L^E(t) + C_{IC}^E(t) + C_{R\&D}^E(t) + \\ + C_D^E(t) + C_{STF}^E(t).$$

Enterprise funds depend on the income and expenditure of funds in the operating, investing and financing activities

$$\frac{d}{dt} R^E(t) = I^E(t) - C^E(t).$$

A household agent represents the subject of the economy of the region, which consists of one independent individual doing the independent housekeeping or, more often, a group of people living together and having a common household (these are more likely families) as well as providing reproduction of human capital. Acting as placement agents and owning economic resources (especially labor), they are sellers in the market of these resources, getting money and other revenues used in the future for the purchase of goods and services. At the

same time, being an attracting agent, the households form the final demand in the market of goods, work and services. The aim of functioning of the agent is to increase the quality and standards of living.

Sources of household agents' income include income from business I_B^H; wage I_W^H; social payments I_T^H; income from the use of property I_R^H; attracted credit resources I_L^H and other benefits I_O^H.

$$\frac{d}{dt}I^H(t)=I_B^H(t)+I_W^H(t)+I_T^H(t)+I_R^H(t)+I_L^H(t)+I_O^H(t).$$

Household expenditure C^H depends on the income and the current rate of consumption $k_C^H \le 1$.

$$\frac{d}{dt}C^H(t)=k_C^H(t)I^H(t).$$

The resulting cash proceeds used by the agent on consumer spending C_U^H (for the purchase of goods and payment of services, implementation of mandatory payments and voluntary contributions, repayment of loans) and creating savings in deposits and securities C_D^H (determined by a conservation coefficient $k_{SD}^H \le 1$)

$$\frac{d}{dt}C_D^H(t)=k_{SD}^H(t)C^H(t);$$

$$\frac{d}{dt}C_U^H(t)=(1-k_{SD}^H(t))C^H(t).$$

Funds of households are represented as follows

$$\frac{d}{dt}R^H(t)=I^H(t)-C^H(t).$$

The market mechanism of interaction of the enterprise agents and household agents is that the first ones act as buyers in the labor market, creating demand for labor, and the latter – as sellers, forming an offer. Regulatory factors are the degree of satisfaction of households prevailing wage conditions (stimulating effect) and increase in other household incomes (decreasing effect).

Budget organization agents are fully contained by the state budget or local budgets and are non-profit.

Agents of the system regarding their roles when interacting during simulation are shown in Fig. 2.

Agents have the ability to learn, adapt and change their behavior, have a dynamic relationship with other agents that can form and disappear in the process of simulation, etc. Each agent in the model is assigned a list of indicators, which being monitored may indicate the imminence of unwanted or offensive (risky) situations. Exceeding the set limits of an indicator's values is the basis for the activation of different mechanisms and situational scenarios. During the simulation, monitoring of state agents, markets, revenues, etc. is carried out.

The complexity of ensuring a coherent interaction between the two sides of the resource management process in which the behavior of some participants is aimed at the formation of reserves (savings), while the behavior

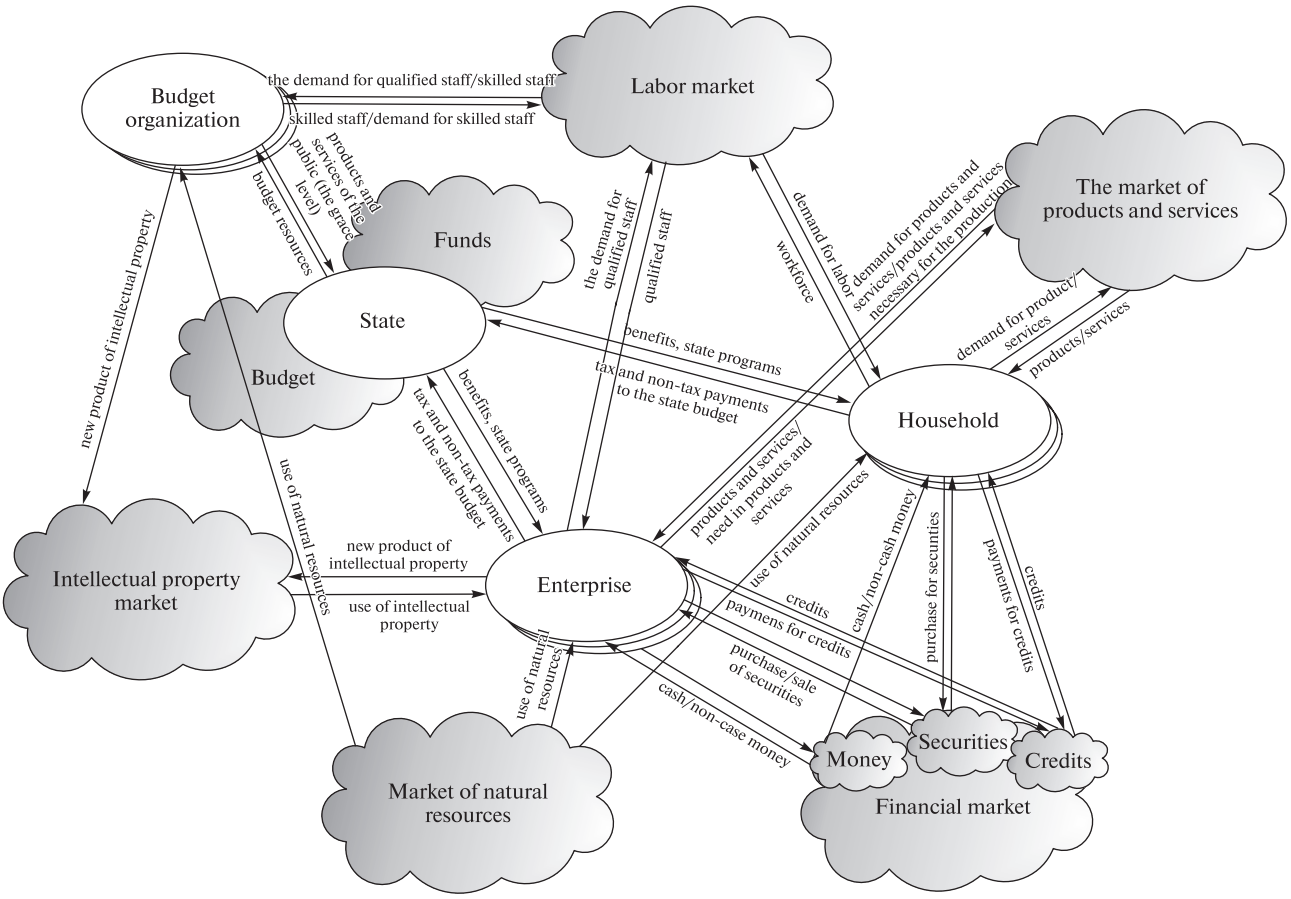

Fig. 2. Agent-based simulation model for the analysis of regional resource management processes

of others is aimed at the formation of the costs (consumption) and is regulated by various factors, resulting in necessity of participation of a meta-level agent (the state), implementing functions of regional management.

The state's influence on the regional economy is exercised through the fiscal system by the following: formation of regional (provincial and local) budgets; direct public investment; providing grants; creating special funds to finance regional programs; attracting foreign investments; concessional lending and taxation; preferences and directions of funds of state budget funds.

The methods of direct economic regulation include targeted financing, direct financial assistance, grants and subventions. For the indirect economic regulation, levers of tax, fiscal, monetary, price, social, foreign economic policies are used. The basis of the regional economic policy is a mechanism for budget management through the establishment of national, regional and local trust funds for the equalization of income in the area, including the provision of appropriate subsidies and subventions. Non-linearity of the relationship parameters of the territorial economic system, the presence of complex overlapping and complementary effects of different factors are prerequisites for the formation of imbalances at various levels. At the level of individual agents, balancing is carried out by determining whether the expenditure strategies of an agent correspond to the volume of available resources.

Within the developed agent-based model a function of meta-level regional management is expressed in the adjustment of the control parameters affecting the behavior of agents in the process of information exchange (cessation of production, increase / decrease in production, diversification, increasing revenue, reduced costs, accelerating revenues, payment delays, provisioning, attracting additional funds, etc.). The vector of control actions includes adjustment of: the volume of investments from the profits of enterprises and organizations; the average monthly salary; the value of the region's consolidated budget expenditures on the economy; the value of the region's consolidated budget expenditures on the social sphere.

The directions presented characterize the budget, investment and social policies of governments at the regional level. Formation of the fiscal policy is aimed at creating conditions contributing to increasing resource potential, which will help to increase the revenue base and revenue budget of the region mainly through the growth of financial and investment potential of the area. Thereby, solving the problem of balancing, a meta-level agent provides the cumulative balance of revenues and expenditures of the territorial economic system.

During the simulation a variety of possible scenarios of regional development upon changing the external and internal conditions are played. Such scenarios can be as follows: increasing the share of fixed income in the budget; resizing payments of local taxes and fees; increasing the deductions from the state taxes to local budgets; changing the rules for granting benefits to local budgets; the development of export and import-substituting industries in the regions which have favorable conditions for that, namely, favorable transport and geographical position, the necessary economic and scientific potential; increase in the production of consumer goods, food products; increase in the agricultural production in the regions in order to maximize food security and increasing export potential, etc.

Conclusions and recommendations for further research. Thus, the proposed approach to the development and use of tools of substantiating the regional development strategies on the basis of agent-based simulation allows carrying out complex experiments based on many interrelated resource flows, requirements, objectives and strategies for the behavior of individual members, the harmonization and adaptation of resource opportunities and interests of subjects.

On the basis of the developed model it is possible to solve a variety of analytical and planning and forecasting tasks: analysis of the main socio-economic indicators of regional development in various sections, as well as the forecast of conditions regarding different types of attracting and allocating resources, monitoring operational violations and further modeling of various balancing mechanisms, etc.

This approach can be applied in practice of the authorities in order to analyze the situation, identify important factors, and improve management efficiency and the accuracy of forecasting the region's development.

A distinctive feature of the multi-agent approach to this problem is the fact that the eventually built agent model allows for the analysis and management of regional resources in real time. Unlike most approaches, which create a kind of virtual environment into which the object model is placed, and where numerous experiments are conducted, here the model agents are started and operate in real time within the environment of a control object. At the same time agents provide automatic response to the information received from the control object, can initiate the launch of modeling, logical and analytical, computational tasks and decision-making.

The developed model was used while developing "Geoinformation System for Resource Monitoring and Analytical Support of Managerial Decisions" (GISRM), which is currently operating in the Office of the communal property of the Kharkiv Regional Council [6]. To date, the system has registered about 200 municipal institutions and enterprises of Kharkiv region. GISRM is used by all participants in the process of regional government at various levels to perform monitoring tasks, operational and strategic planning, forecasting, and make effective management decisions. GISRM provides solutions to logical-analytical problems and the formation of estimates and projections on the basis of objective information about available resources and the results of their use, which ensures the effectiveness of management decisions.

Apart from providing electronic document management for the Office of the communal property of the Kharkiv Regional Council, GISRM allows controlling the fulfillment of the plan target of financial and economic activities of utilities, targeted and effi-

cient use of public property, following the economical and rational use of budgetary funds by utilities, controlling the timely accrual and transfer of lease payments to the budget, obtaining additional revenues to the regional budget, identifying cases of unsound spending of budget funds, etc.

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Мета. Підвищення ефективності управління регіональними ресурсами на основі самоорганізації та адаптації в мультиагентних системах в умовах невизначеності та динамічного оточення.

Методика. Проведені дослідження ґрунтуються на використанні методів системного аналізу при виборі напрямів моделювання процесів управління регіональними ресурсами; імітаційного моделювання та теорії багатоагентних систем для розробки агентної імітаційної моделі управління регіональними ресурсами.

Результати. Проведено аналіз особливостей управління регіональним розвитком та існуючих підходів і методів аналізу й прийняття рішень у цій області. Розроблена структура агентної імітаційної моделі управління регіональними ресурсами.

Наукова новизна. Розроблена агентна імітаційна модель управління регіональними ресурсами з можливостями економічної самоорганізації та колективної адаптації елементів моделі з власними інтересами й процесами прийняття рішень, що дозволяє вирішувати завдання децентралізованого планування з гнучким управлінням ресурсами в умовах динамічного оточення.

Практична значимість. Розроблена модель являє собою науково-методичну основу для створення інструментальних засобів прийняття управлінських рішень, що забезпечують планування розвитку та ефективного використання регіональних ресурсів.

Ключові слова: *регіон, ресурси, ресурсний потенціал, агентна модель, регіональний розвиток*

Цель. Повышение эффективности управления региональными ресурсами на основе самоорганизации и адаптации в мультиагентных системах в условиях неопределенности и динамического окружения.

Методика. Проведенные исследования основываются на использовании методов системного анализа при выборе направлений моделирования процессов управления региональными ресурсами; имитационного моделирования и теории многоагентных систем для разработки агентной имитационной модели управления региональными ресурсами.

Результаты. Проведен анализ особенностей управления региональным развитием и существующих подходов и методов анализа и принятия решений в этой области. Разработана структура агентной имитационной модели управления региональными ресурсами.

Научная новизна. Разработана агентная имитационная модель управления региональными ресурсами с возможностями экономической самоорганизации и коллективной адаптации элементов модели с собственными интересами и процессами принятия решений, что позволяет решать задачи децентрализованного планирования с гибким управлением ресурсами в условиях динамического окружения.

Практическая значимость. Разработанная модель представляет собой научно-методическую основу для создания инструментальных средств принятия управленческих решений, обеспечивающих планирование развития и эффективного использования региональных ресурсов.

Ключевые слова: *регион, ресурсы, ресурсный потенциал, агентная модель, региональное развитие*

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