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Development and testing of the toolkit of strategic planning of territorial development on the basis of an intelligent adaptive simulation model*

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Abstract

Management of strategic development of Russian regions is a complex task, the solution of which is associated with a set of difficulties of methodological nature. In particular, there is a low quality of formed forecast assessments on the main parameters under consideration. Despite the availability of research in this area and regulatory legal framework, strategic planning documents in Russia are often not linked to each other, are repeatedly revised in the course of implementation and, ultimately, are not fully implemented. This is largely due to the fact that the available scientific potential is not fully utilized, including the development of relevant information systems. The aim of this research is to develop a decision support toolkit for strategic planning of regional development. Agent-based modeling, adaptive management, data mining and scenario modeling are used as the main research methods. In the course of the research, the concept of toolkit formation is proposed based on the construction of an intelligent adaptive simulation model (IASM), taking into account the theory of strategic planning and the ability to process heterogeneous data. The proposed structure of IASM includes four interrelated hierarchical levels – intelligent agents, macro-processes, management system and external environment. Special attention is paid to the development of a model of adaptive behavior of an intelligent agent. The proposed approach to implementation will make it possible to cover the whole range of tasks – from the analysis of input data to the development of management decisions. The software implementation of the model thus developed is carried out using the AnyLogic toolkit.

Keywords: strategic planning, territorial socio-economic systems, simulation model, adaptive management, intellectual analysis, decision support system, agent-based approach

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Introduction

The basis for making any decision in the field of managing the development of territorial socio-economic systems is a clear scientifically substantiated idea of how its implementation will affect the change in the values of all key indicators that characterize this system. Thus, the functions of forecasting and planning as constituent elements of the management system are actualized. At the same time, the formation of long-term development forecasts requires from the decision maker a much greater amount of knowledge, background information and experience compared to the solution of operational management issues [1]. It is strategic management and the development of regional development strategies that require appropriate information support tools [2]. It should be noted that there are significant developments in this area in relation to manufacturing enterprises [3].

Under these conditions, the problems of developing approaches, methods and tools for forecasting and strategic planning in the field of development of the constituent entities of the Russian Federation that take into account these challenges are becoming more relevant. At the same time, today in this sphere there are a number of difficulties [4–7] associated with the inconsistency and contradiction of the goals outlined in the documents of strategic development, insufficient use of management information and the level of staff training. Also, the actual priority of tactical level issues against the background of low elaboration of strategic management of the region has a significant impact. As a result, the resulting forecast assessments and decisions often require revision and adjustment.

This is largely due to the existence of methodological problems in strategic planning and management which are based on a complex set of interagency approvals. Today, this problem has not been solved even at the highest level. The presentation by the Ministry of Economic Development of the Russian Federation of the updated Strategy of Socio-Economic Development until 2023, scheduled for May 14, 2021, never took place. In fact, it was announced that a transition to the development of a certain broad list of "new initiatives" was underway. One of the reasons for this situation is the harsh criticism of the draft Strategy by academic economists, who concluded that this document "continues the tradition of regularly violated plans." Similarly, the annual report of the Accounts Chamber of the Russian Federation states that "the system of strategic planning is currently unbalanced and inefficient, insufficiently methodologically ensured, with a low level of control and executive discipline; a system of strategic planning is absent; the goals of the authorities are not linked with each other and with the requirements of the President of the Russian Federation and they do not dock with the project activities of the Government of the Russian Federation; moreover, they are defined formally, and their achievement is not controlled" [8]. Back in 2017, the representative of the Ministry of Economic Development of the Russian Federation noted the discrepancies in the strategic planning documents, in particular, differences in the names of the same indicators, inconsistency in the values of target indicators, lack of balance and consistency within the documents, as well as lack of skills to work with such data. Among the main tasks was the creation of a digital platform by 2020 which would enable the automation of the strategic planning process from the moment a decision is made to develop a document to its completion and performance evaluation. To achieve this task, it was assumed to use big data, methods of simulation modeling, artificial intelligence and cloud technologies [9].

Many other experts also note that the current strategic planning documents of different levels in Russia (about 54 thousand units), although developed on the basis of the Federal Law No. 172 "On Strategic Planning in the Russian Federation", are not linked to each other [10–12]. In fact, scientists and specialists have already openly stated that in the current conditions the strategic level is subordinated to operational and tactical tasks, which is fundamentally contrary to the logic of formation of any effective management system.

High risks and costs associated with making wrong and inefficient decisions require careful consideration and evaluation of possible alternatives [13]. The availability and reliability of information plays an important role.

The aim of the research is to develop decision support tools for strategic planning of regional development. We must integrate management models, knowledge processing technologies and modeling tools in a single information field, as well as to propose methods for their incorporation into the existing planning system. At this stage, we propose to create a methodology and concept of information support for the processes of strategic planning of socio-economic development of macro- and meso-level systems on the basis of system integration of adaptive management models, intellectual knowledge processing technologies and simulation modeling.

AnyLogic system was chosen as a tool environment for simulation modeling. This software solution has a number of undeniable advantages: it is a professional tool for agent-based modeling, it is integrated with GIS maps, has extensive animation and visualization capabilities and is able to process big data as input for the model. A distinctive feature of AnyLogic is also the ability to combine different modeling paradigms; for example, system dynamics methods can be applied in agent-based models. Experiments based on simulation models built in AnyLogic allow us to perform scenario calculations and optimize resource planning.

1. Concept of research and development of an intelligent adaptive simulation model

The decision support (DS) toolkit in the creation of the development strategy of the constituent entities of Russia is primarily based on an understanding of the tasks that will be solved using it. For this purpose, the range of solutions that require justification should be defined. At the same time, the development of a regional development strategy is not a goal, but a mechanism for achieving the goals of regional development. That is, more general goals determine private goals. Thus, having analyzed the objectives of regional development strategy development as a document and its structure, we concluded that the ultimate goal of the DS toolkit should be a scientifically justified set of values of the managed parameters. At the same time, when using the developed toolkit, in our opinion, other related tasks can be solved, including:

1. Assessing the observed and retrospective state of the regional system, identifying its strengths and weaknesses, analyzing and monitoring indicators.
2. Development of a scenario development forecast, including a baseline scenario under current conditions, and analysis of possible results of the implementation of certain strategic management measures.
3. Determining the value of controlled parameters required to achieve a given value of a target parameter under given constraints, and solving planning problems.
4. Identify a set of recommended activities within the decision support task.

Based on this, the requirements for decision support tools are determined [14]. In the management of regional development, we can rather conditionally distinguish two levels – operational and strategic management. In the first case, the goal is to eliminate current problems, in particular, related to the need to achieve individual elements of strategic objectives. In turn, strategic management establishes priorities for the development of the regional socio-economic system (RSES), key parameters, as well as goals for the operational level. Thus, the parameters of the region's development are influenced by the control parameters – the results of the management subjects' activity. In addition to this, the dynamics of RSES parameters are affected by the processes occurring both in the system itself and in the external environment.

It should be clarified that in the framework of the ongoing research under intelligence in an intelligent adaptive simulation model (IASM) we understood the ability to work with knowledge, poorly structured information due to the presence of appropriate components (knowledge base, rule base, application of fuzzy logic methods, etc.) in addition to the capabilities of simulation models built on the basis of generally accepted approaches. At the same time, adaptability is implemented through behavioral algorithms that minimize planning errors through the step-by-step adjustment of economic agents' strategies [15].

The core of the toolkit is the economic and mathematical model of the RSES (*Fig. 1*). In this case, as it was shown above, the dynamics of regional socio-economic processes are determined by the set of decisions made by individual agents with the properties of adaptability capable of perceiving information, processing it and forming logically justified decisions on its basis, i.e., intellectual functions. In this regard, we propose to use the agent-based approach as the basis of the model developed.

Within the framework of building economic and mathematical models of the development of the RSE based on the principles of agent-based modeling, all agents should be described through a set of quantitative development indicators and mechanisms used to achieve them. The development of these mechanisms is one of the most difficult tasks, as they describe the agent's decision-making behavior. These actions are based on work with information related to receiving, storing, processing and using. Interaction with the external environment is also an exchange of information, i.e., values of some parameters.

In our opinion, it is the availability of the ability to form logically valid conclusions and adapt the agent through its training that allows us to obtain the most suitable model of the real RSES. In this regard, we propose the development of IASM.

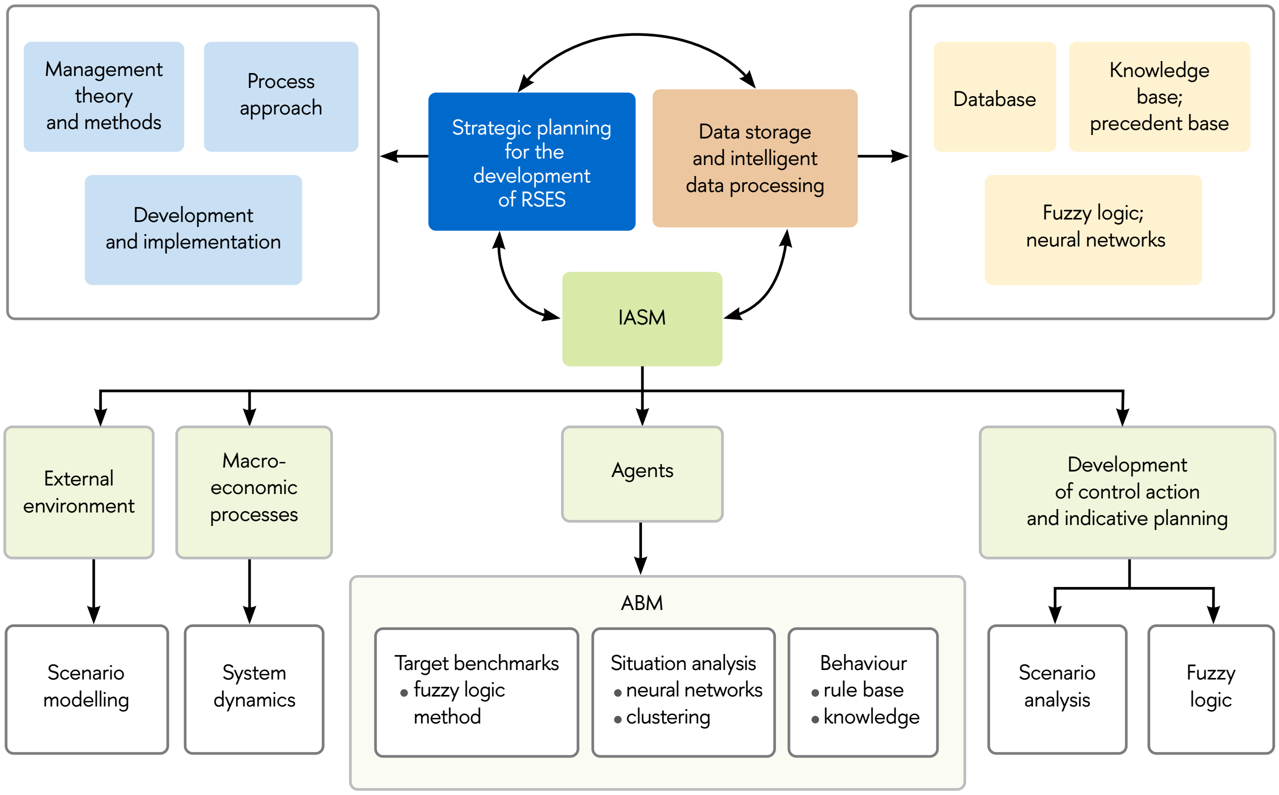

Fig. 1. Concept study and toolkit development.

At the same time, it is obvious that for the description of many macroeconomic processes it is more logical to use methods that do not require us to describe the behavior of individual agents, i.e., with a higher level of aggregation [16]. In this regard, it makes sense to reflect some macroeconomic processes using dynamic modeling and other methods. Such a combination of different approaches optimizes the costs of development and operation of the model of a socio-economic system.

The novelty of our statement of the problem and the proposed research concept, in our opinion, lies in the assessment of the possibility of applying the class of adaptive management models [17] and methods of intelligent knowledge processing widely used in the theory of decision-making in complex human-machine systems to formalize the bounded-rational logic of the behavior of economic agents at the regional level when implementing their development strategy in a competitive market environment.

In its theoretical aspect, the distinctive feature of the proposed approach is the consideration of the region not from the position of macroeconomics, within the framework of which aggregated processes do not allow us to see the contribution of their individual components, but from the position of the balance of macro- and micro-level representation, which is reflected both in the methodology of managing the development of the object and in the simultaneous use of two paradigms of simulation modeling – system dynamics and the agent-based approach to solve the relevant problems. This manifests itself in the focus of the proposed research on the integration of knowledge about the research object requiring specific methods and approaches to study its individual elements.

In its instrumental aspect, the originality of the proposed model of information support organization, in our opinion, consists in the logical-hierarchical composition of a set of behavioral, agent-oriented and management models in a single information environment. Unlike previously developed approaches, this allows us to form strategies for the development of regional systems coordinated by hierarchy levels and developed taking into account the goals and interests of agents and strategic development plans of the region as a whole.

2. Structure of an intelligent adaptive simulation model

The approach presented here is based on the application of formalized methods of analysis, forecasting and planning. The development of the corresponding toolkit implies, first of all, the formation of its core – an intelligent adaptive simulation model. To describe it, in our opinion, it is necessary to define the structure of the model, as well as the methodological and informational basis for its formation. The general structure of the IASM is presented in *Fig. 2*.

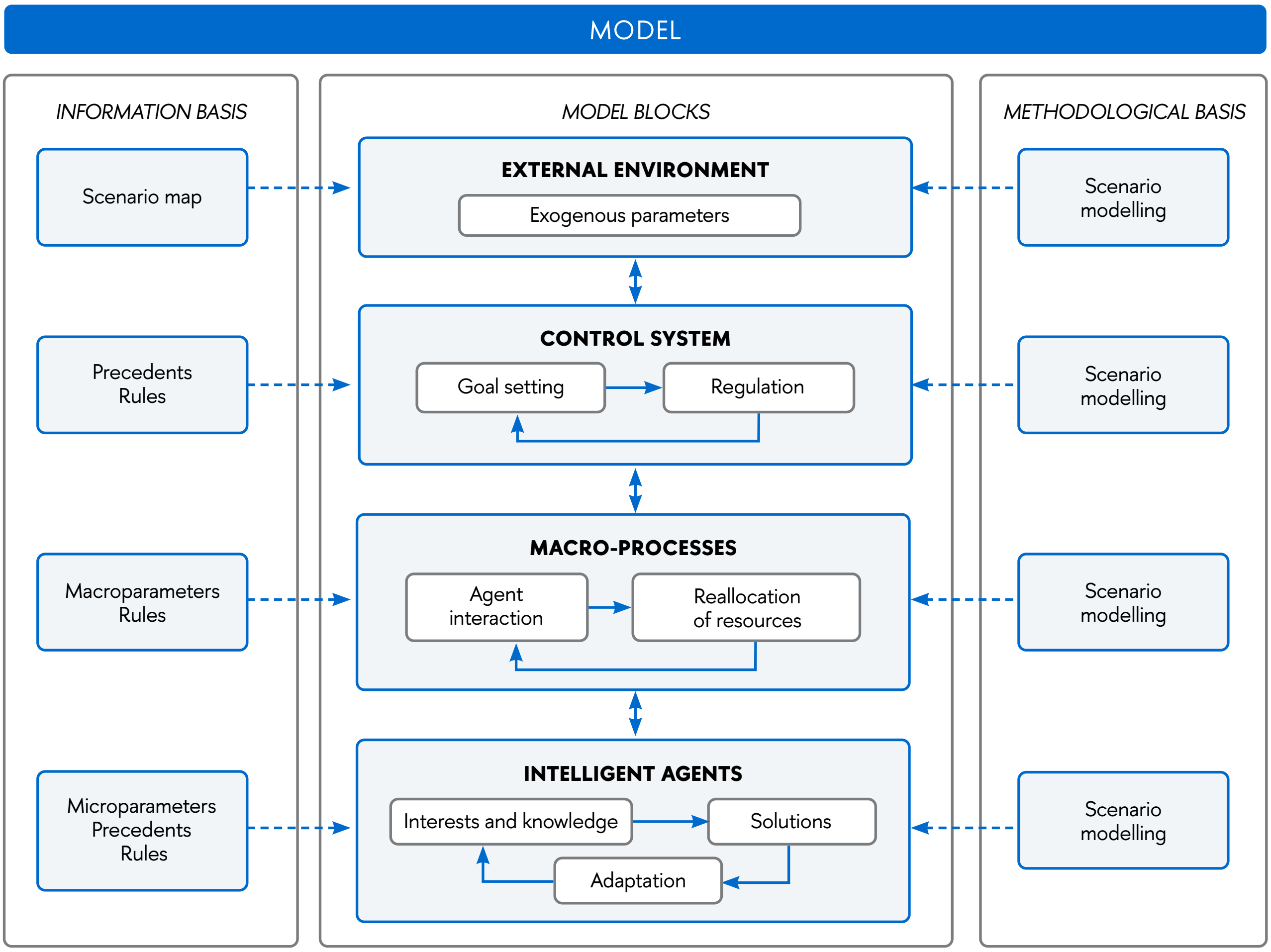

Fig. 2. Structure of the intelligent adaptive simulation model.

The RSES model includes several levels.

1. The level of intellectual agents reflecting the functioning of individual agents and small social groups. Each of them has its own interests, which are largely conditioned by the situation in which it finds itself. Within the framework of the model, an agent compares the parameters of a given situation with the expected characteristics and makes decisions based on this. To model the procedure of analyzing and classifying the situation, we propose to apply neural network technologies and methods that allow us not only to make a choice between already known options, but also to identify those belonging to previously unknown situations [18]. At the same time, decision making can be based both on the use of rules (in the case of clearly defined requirements for the agent's actions) and on the basis of precedents (in the case when there is no rule and there are many known options). If the situation is fundamentally new, a new solution must be developed, which is also a manifestation of the agent's intelligence. In this case, the description of its behavior is based on the theory of bounded rationality [19] within the framework of which the decisions taken will not necessarily be optimal. The implementation of each decision and the evaluation of its consequences lead to the expansion and adjustment of its knowledge base and precedent base, i.e. adaptive learning of the agent takes place. Due to this, with the appearance of new precedents, the next decisions can be made according to new rules. In general, the functioning and development of an agent is described within the framework of the agent-based modeling (ABM) methodology, the use of which in relation to complex socio-economic systems is considered in the works of a number of authors [20, 21].

2. The interaction of many individual agents generates macroeconomic processes. At this level of aggregation, it becomes too costly to consider each agent separately. In this regard, a set of macroeconomic agents is considered. The ratio of stocks of various resources of these agents forms the structural model of the economy. At the same time, resources can be transferred from one agent to another and transformed. All this is proposed to describe using the methods of system dynamics. In interaction each agent has its own interests. Interaction in market conditions is possible only if the interests are coordinated.

3. The control system is a setting above the model of the region and serves for setting target indicators and regulators. If the actual values of the indicators do not correspond to the previously set values, the regulators are adjusted first. However, if this does not have the expected effect under the existing constraints, the values of target indicators are adjusted. In this case, the choice of decision (to change the values of regulators or target indicators) is based on the analysis of the situation and adaptive management.

4. The development of the regional system is significantly influenced by the external environment, which is described by a set of exogenous parameters. In the framework of this study, they are independent of the processes occurring within the RSES. The values of exogenous parameters are set using scenario maps.

Thus, the structure of the intellectual adaptive simulation model describes a set of socio- economic relations implemented at different levels in the most generalized form. In this case, its basis is the functioning of intelligent agents.

3. Model of adaptive behavior of an intelligent agent

The behavior of an intelligent agent is described within the framework of the developed model through its decision-making aimed at satisfying its own interests under the existing conditions of functioning, taking into account the available knowledge (rules, precedents, known situations and solutions), as well as the possibility of agent adaptation. The adopted and realized decision determines the change in the agent's parameters and influences the characteristics of the external environment. As stated above, the agent functions under conditions of incomplete and contradictory information. Its actions can be described by the theory of bounded rationality. This concept in the classical sense characterizes the situation in which a person considers a small number of options that differ significantly and chooses the option closest to his aspirations, which does not guarantee the maximization of utility [22, 23]. In the framework of the proposed model, this situation can be represented by a set of possible decisions of the agent, realized with some probability. Based on previous experience and available knowledge, the agent chooses a solution that satisfies him, which does not indicate the optimality of the choice made, i.e., the consideration of the entire possible set of solutions.

Based on these assumptions, the research has developed a model of agent decision making (*Fig. 3*), based on the application of a set of methods of agent-based modeling, situation classification, theory of bounded rationality, application of rule bases and precedents, data analysis, and others.

The totality of information defines the situation in which the agent finds itself. Identification of a situation consists in attributing it to some known class or, if necessary, allocating a new class. The set of situations known to the agent forms a part of the agent's knowledge base – the "Situation Base".

Another part of it is the "Decision Base", which contains information about what actions the agent can perform (a list of controllable parameters and their characteristics). The functioning of an intelligent agent is a set of decisions it makes $Rh = \{Rh_t^1, Rh_t^2, ..., Rh_t^n\}$ based on the prevailing class of situation $K = \{K_t^1, K_t^2, ..., K_t^n\}$ at time t.

The choice of a decision option is based on the rules and precedents available to the agent, which are contained in the "Rules Database" and "Precedents Database," respectively. They describe what actions and with what probability the agent chooses in this or that situation. Referring to these databases allows us not only to correlate the observed conditions and decisions, but also to determine the expected consequences of their realization (expectations). At the same time, actions that cannot be performed (there are no conditions for their performance) have zero probability of choice, i.e., they are actually excluded from the list of possible decisions of the agent.

The rule base includes conditions $U = \{U_t^1, U_t^2, ..., U_t^n\}$, decisions and expected outcomes $Rz\_r = \{Rz\_r_t^1, Rz\_r_t^2, ..., Rz\_r_t^n\}$, and it is subscribed to by a tuple of elements $Ru = \langle U, Rh, Rz\_r \rangle$. In turn, the precedent database contains decisions $Rh\_b = \{Rh\_b_t^1, Rh\_b_t^2, ..., Rh\_b_t^n\}$, made in a previously observed situations $K\_b = \{K\_b_t^1, K\_b_t^2, ..., K\_b_t^n\}$, and information about previously observed outcomes $Rz\_b = \{Rz\_b_t^1, Rz\_b_t^2, ..., Rz\_b_t^n\}$. The precedent database is described by a tuple of elements $Pr = \langle K\_b, Rh\_b, Rz\_r \rangle$.

A precedent is an incident or event that took place in the past and serves as an example or a basis for subsequent actions in the present [24]. On this basis, precedents are a reflection of the agent's experience and knowledge about the relationship between events and phenomena. The result is a list of indicators that have changed their value after the realization of an action and are associated by the agent with the consequences of this action, as well as the significance of changes in these indicators.

In this case, priority is given to the use of the rule base, as it contains more stringent requirements for the definition of the solution laid down in normative form or as a result of repeated precedents. At the same time, the rule base is not unchangeable. It can be replenished and adjusted.

The use of the precedent database implies accessing it and searching for the situation most similar to the current one. For this purpose, the parameters of the current situation are compared with the existing conditions of known precedents. It should be noted that the search for a precedent is carried out not by an individual indicator, but by the whole set of indicators that form the situation. In this case, we are talking about reasoning on the basis of precedents, which in a broad sense is a method of solving new problems on the basis of already known solutions. Reasoning on the basis of known situations is a special case of reasoning by analogy.

Speaking about situation identification, it should be understood that the agent needs not only to determine its position among many other variants of situation development in this area, but also to determine how familiar it is to him. Thus, if the agent has previously encountered it, this situation can be called known and known solutions can be considered for it. Otherwise,

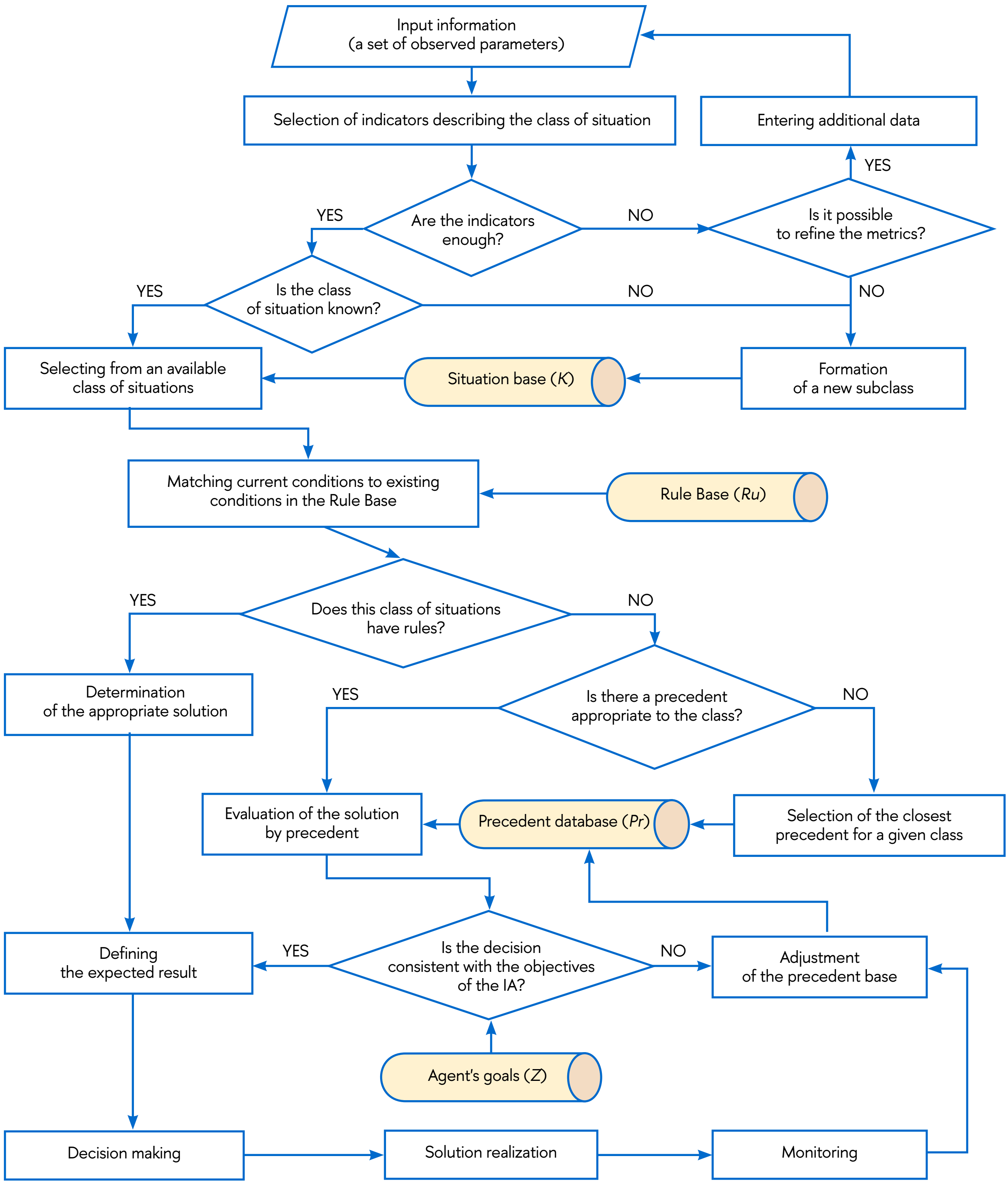

Fig. 3. Model of decision making by an intelligent agent.

the agent has no experience of behavior in this situation, and the decision can be made on the basis of the closest known one. Thus, the intelligent agent, analyzing the current situation, compares the actual conditions *U_f* with the conditions contained in the rule base *U_b*, and if a match is found, applies the corresponding rule *Rh*. If there is no rule, the available precedents are considered and the most coincidental to the actual and previously observed situation is identified among them.

One of the main properties of an agent is the presence of its target attitudes. In the framework of this study, the agent's target attitudes are understood as a set of the agent's ideas about which parameters are significant indicators and which of the directions of changes in the values of indicators of its development is more preferable, as well as what is the ratio of the significance of target indicators among themselves. Thus, in terms of the formation of the agent's target orientations, we can distinguish three fundamental issues:

1. What are the target benchmarks for this agent, i.e., the composition of parameters that are attributed to the target indicators?
2. What is the desired value of the agent's target benchmarks, i.e., some quantitative measurement of these target indicators;
3. How do the values of certain goals of the agent relate to each other?

The most important benchmarks for the development of society are defined in the Decree on the National Development Goals of the Russian Federation for the period until 2030 and in the perspective until 2036. Based on them, it is possible to identify a number of indicators for quantitative assessment of the functioning of economic agents, including the following:

- ♦ increase in the total fertility rate;
- ♦ increasing life expectancy;
- ♦ poverty reduction;
- ♦ provision of housing for citizens;
- ♦ ensuring the growth rate of the country's gross domestic product above the global average;
- ♦ increase in the volume of investments in fixed capital;
- ♦ ensuring sustainable growth of the population's income, etc.

As can be seen, despite the fact that the indicators themselves are quantitatively measurable, the target attitudes have qualitative characteristics. This fact allows them to reflect more adequately the behavior of real people whose targets can be described as "increase in monetary income," "increase in the level of environmental safety of places of residence," etc., and the ratio of importance between them is described by the concepts of "significantly more important," "somewhat more important," etc. That is, we are talking about the application of indicators described using fuzzy logic methods. An example of combining this approach and agent-based modeling is available in [25].

The realization of the agent's set goals is carried out through the choice of decisions aimed at changing the controlled parameters under certain conditions that form the situation faced by the agent. Analyzing the existing conditions, the agent determines to which of the known classes this or that situation belongs. To do this, it needs to have an appropriate knowledge base, including a description of situations, and a tool for their identification and classification. It is proposed to use clustering methods to determine the class of a situation.

The behavior of an economic agent is largely determined by the information it possesses. The following sources of information can be distinguished: 1) information from the external environment, the parameters of which do not depend on the agent himself; 2) information that was formed during the interaction of the agent with the external environment; 3) information characterizing the agent himself, the receipt of which does not require interaction with other agents or the external environment.

Speaking about the set of parameters characterizing the agent itself, it should be noted that this group of indicators also includes the resources possessed by the agent. In this sense, there is a relationship between resources and controlled parameters of the agent. In fact, the agent's behavior is a change in the values of these parameters. As part of the formation of the economic-mathematical model, information about the list of these indicators and their characteristics are contained in the agent's decision base. It should be emphasized that, in a broad sense, the list of these indicators is not only not the same even for agents of the same type, but also is not constant over time. If we consider the agent "Human", the list of controllable parameters and possibilities to change their values depend on age, social status, place of residence, etc. However, from the point of view of solving practical modeling issues, it seems reasonable to establish a common list of controllable parameters for all agents of the same type, but defining for each of them different possibilities of adjusting its values. More difficult in terms of formalization, in our opinion, is the problem of the emergence of fundamentally new controllable parameters as a result of changes in external conditions, scientific and technological progress and human creativity. It should be noted that the list of controllable parameters depends to a significant extent on the level of detail of the model and its general focus on the solution of certain problems.

Based on the generalized scheme we have presented, the behavior of each of the agents under consideration was formalized.

The functioning of the economic agent "Human" is multidimensional. Decisions made by him affect issues in all spheres of life and, depending on the chosen level of detail, may include both strategic issues (e.g., place of residence, change of occupation, choice of training direction in higher education, etc.) and everyday issues, the solution of which is referred to the operational level and is often "mechanical" in nature.

For this economic agent, the research conducted proposes to consider decision making in three aspects:

- change of place of residence (migration);
- revenue generation;
- cost formation.

Let us consider the second question in more detail, since in many respects its solution determines the parameters of the situation for others (*Fig. 4*).

Adaptation of an economic agent to a changing situation consists in changing the rules of its behavior depending on certain conditions.

The key goal of the agent in this direction is to obtain income not lower than expected. It should be emphasized that in this case, as mentioned earlier, it is not about maximizing the values of the parameter, but about satisfying some given level.

From the set of characteristics of the agent "Human" it is required to select those that are significant from the point of view of solving the given problem. In this case, the characteristics can be selected from different groups – Demographics (gender, age), Education (level of education, direction of training), Work (length of service, experience of entrepreneurial activity, current status of professional activity), Finances of the population (current and retrospective level of income). On the other hand, the agent's decision is influenced by the state of the environment in which he/she is located, including the characteristics of the economic activities under consideration from the point of view of a potential employee (level of remuneration, availability of vacancies) and from the point of view of an entrepreneur (level of competition and availability of demand for FEA products). The combination of these characteristics determines certain situations which are supposed to be identified by cluster analysis. Given the multitude of possible values of these characteristics, it is not possible to determine in advance the exact number and parameters of each situation, but it is obvious that the decision made by a young specialist with no experience of entrepreneurial activity in the conditions of economic recession and excess of personnel on the labor market will be significantly different from the decision of an entrepreneur with experience in the market, where there is an increase in demand. At the same time, the differences in decisions are caused not only by the difference in the values of factors, but also by the rules applied by agents. Since the establishment of deterministic relationships between conditions and decisions in this case is not possible (including due to the impossibility of full formalization of conditions and their quantitative assessment, as well as unambiguous attribution of the observed combination of conditions to a particular class of situations), it seems reasonable to choose a solution using intelligent algorithms, including those based on fuzzy logic methods.

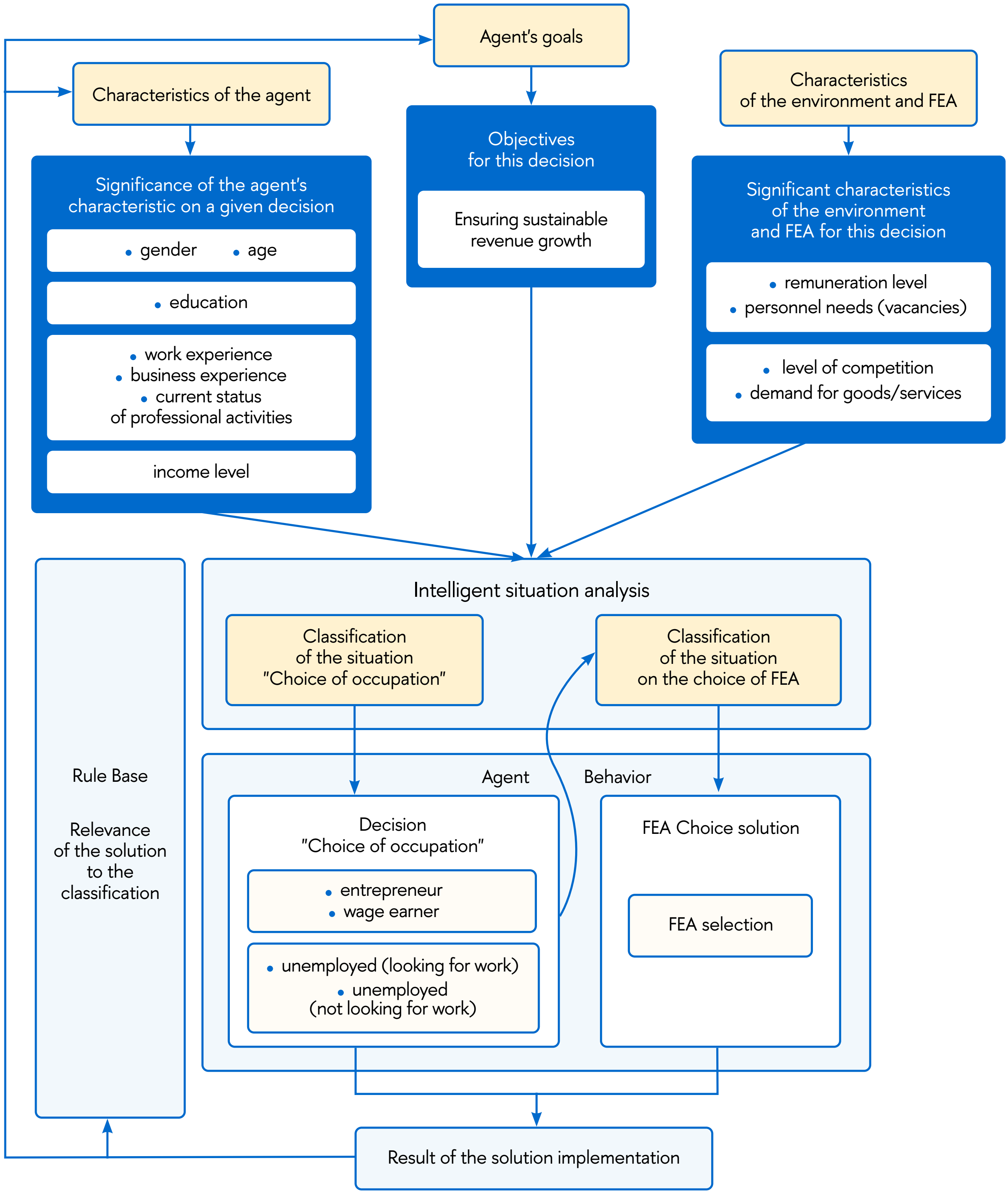

Fig. 4. Formation of income of the agent "Human".

These rules can be transformed as a result of experience gained during the implementation of previously made decisions. Moreover, this experience may lead to changes in the agent's target attitudes. This procedure implements not only the possibility of adaptation of the economic agent to changing conditions, but also the adaptation of the rules of behavior of the agent itself.

With respect to other economic agents and decisions, it seems reasonable to formalize the decision selection procedure in a similar way.

At the same time, the calculation of other parameters of functioning of the economic agent "Human" is realized within the framework of the set of equations presented below.

One of the key subsystems of the model is the demographic block, including the description of population movement. These processes lead to changes in the number of groups. The method of age movement is used in the modeling toolkit. Taking into account the gender aspect increases the adequacy of the reflection of the processes. N gender and age groups are included in the study: $\forall n, n = \overline{1;N}$.

$$P_t^n = P_{(t-1)}^{(n-1)} + B_t^n - D_t^n + M_t^n,$$

where P_t^n – population;

B_t^n – number of birth (for the first age group);

D_t^n – number of deaths;

M_t^n – balance of migration flows.

The number of births in the t-th year is calculated based on the birth rate kB_t using the formula:

$$B_t^n = kB_t \cdot P_t \cdot k_{m/w},$$

where $k_{m/w}$ is the gender distribution coefficient.

It should be taken into account that the fertility rate depends on a set of heterogeneous factors, including the number of women of fertile age, marriage rate, income level of the population and housing availability of the population.

The values of these factors are determined based on the logic of the model formation. For example, the number of wages, as an element of the level of income of the population, is determined by the interaction of the economic agent "Business" within the framework of the policy to attract labor force and the agent "Human" within the framework of making decisions on the formation of their own income. In turn, the volume of the total area of residential premises is determined by the results of the implementation of the consumer function by the agent "Human", i.e., his decision-making with regard to the use of own and borrowed financial resources.

The economic essence of the agent "Human" is realized in the formation and use of financial resources. The key sources of income InH_t^{Σ} are entrepreneurial activity InH_t^{en}, labor remuneration InH_t^{w}, social transfers InH_t^{tr}, property income InH_t^{prop}, and other income InH_t^{of}. In addition, credit resources can be considered InH_t^{cr}.

$$InH_t^{\Sigma} = InH_t^{en} + InH_t^{w} + InH_t^{tr} + \\ + InH_t^{prop} + InH_t^{of} + InH_t^{cr} + StH_{t-1}.$$

The most important source of monetary income today is labor remuneration. In this case, the level of labor remuneration and the number of employees of enterprises and organizations are determined within the framework of the proposed model on the basis of the market mechanism of interaction of economic agents.

To formally describe the income strategy of the economic agent "Human", a procedure of adaptive behavior on the labor market is provided in which a sequential choice of the type of activity an FEA takes place. The agent evaluates the attractiveness of each of the four options – employment, entrepreneur activity, status of unemployed, job seeker and unemployed who is not looking for a job at the moment. Based on a set of characteristics of the agent and the environment, a choice is made in favor of one of the options. From a macroeconomic point of view, the number of workers L_t^w depends on the value of wages Wg_t, the number of the working-age population P_t^{em} and the amount $InH_t^{\Sigma n-p}$. That is, the balance of supply and demand in the labor market is considered. However, in contrast to purely balance methods of calculation, the proposed approach is based on the adaptive behavior of an intelligent agent capable of assessing the economic situation and preferability of choice. Due to this, at each step of the iterative algorithm the adjustment of the number of employed in the economy by value λ^L is realized.

Similarly, the behavior of the agent with respect to the formation of its other parameters is described, and the description of the rest of the agents in the system is carried out.

Thus, one of the distinctive features of an intelligent agent is its ability to adapt to changes in the conditions of functioning. In this case, we are talking not only about adjusting quantitative parameters, but also about changing the qualitative component of the agent's behavior which manifests itself in two aspects:

1. Choosing different courses of action under different conditions.
2. An agent's ability to learn.

The first component is associated with the determination of changes in the values of the controlled parameters. However, it is the agent's learnability that provides the possibility of its representation as a full-fledged and independent subject of economic relations and thus forms the essence of the agent-based approach to modeling and the basis of an intelligent adaptive model.

In the framework of the current research, learnability is considered as the possibility of adjusting the rules of behavior. If the agent's rules of behavior are variants of actions in a given situation with a certain probability of choosing one or another action, then in this aspect learning is based on adjusting the probability of choosing each of them. The agent does not just make a choice of this or that action, but also forms a certain expectation. If the observed parameters confirmed his expectations, then the decision made (the chosen action) is perceived by the agent as correct and the probability of its use in a similar situation is preserved. If a different result was obtained than expected, the probability is corrected. At the same time, the agent's learning should not be limited only to changing the parameters of choosing one or another already known action. As noted earlier, the agent can supplement its knowledge base and, in some cases, adjust the goals of functioning and its own interests. It should be noted that adjusting the values of an agent's target indicators when they cannot be achieved is consistent not only with the notion of adaptation of agent behavior, but also with critical research on agent behavior [26].

As part of the testing of the proposed IASM toolkit, agent-based models were developed to describe one of the most important tasks of strategic planning – the regulation of migration and demographic processes at the regional level. *Figure 5* shows a fragment of the agent-based model interface, which allows us to determine the dynamics of migration flows between federal districts of the Russian Federation.

The regulated parameters in the model are the average wages in the region, the volume of investment in fixed capital, as well as the integral index of the population's quality of life. Such models allow us, in particular, to form balanced schemes of territorial population distribution, to justify the conditions and mechanisms for reducing disproportions in the socio-economic development of individual territories, caused, among other things, by low population density and lack of qualified personnel for the regional economy. The blue dots on the map show the agents representing the permanent population of the region, and the red ones – migrants. The drop-down menu makes it possible to compare territories by the parameters of population size and density, average wages, and volume of investment in fixed assets. The model outputs are diagrams illustrating the projected ratio of migrants to the permanent population, as well as the dynamics and direction of migration flows. A separate sheet calculates the statistics of arrivals/departures for each federal district in relation to the selected "base" territory (*Fig. 5* shows the example of the Republic of Bashkortostan).

4. Application of an intelligent adaptive simulation model in strategic planning

The use of IASM as a fundamental component of decision support systems (DSS) in the field of strategic planning implies the use of the toolkit's capabilities at all key stages of the process under consideration. At the same time, the most important function is the development of a forecast of socio-economic development of the territory, taking into account the peculiarities of the behavior of all parties involved, including

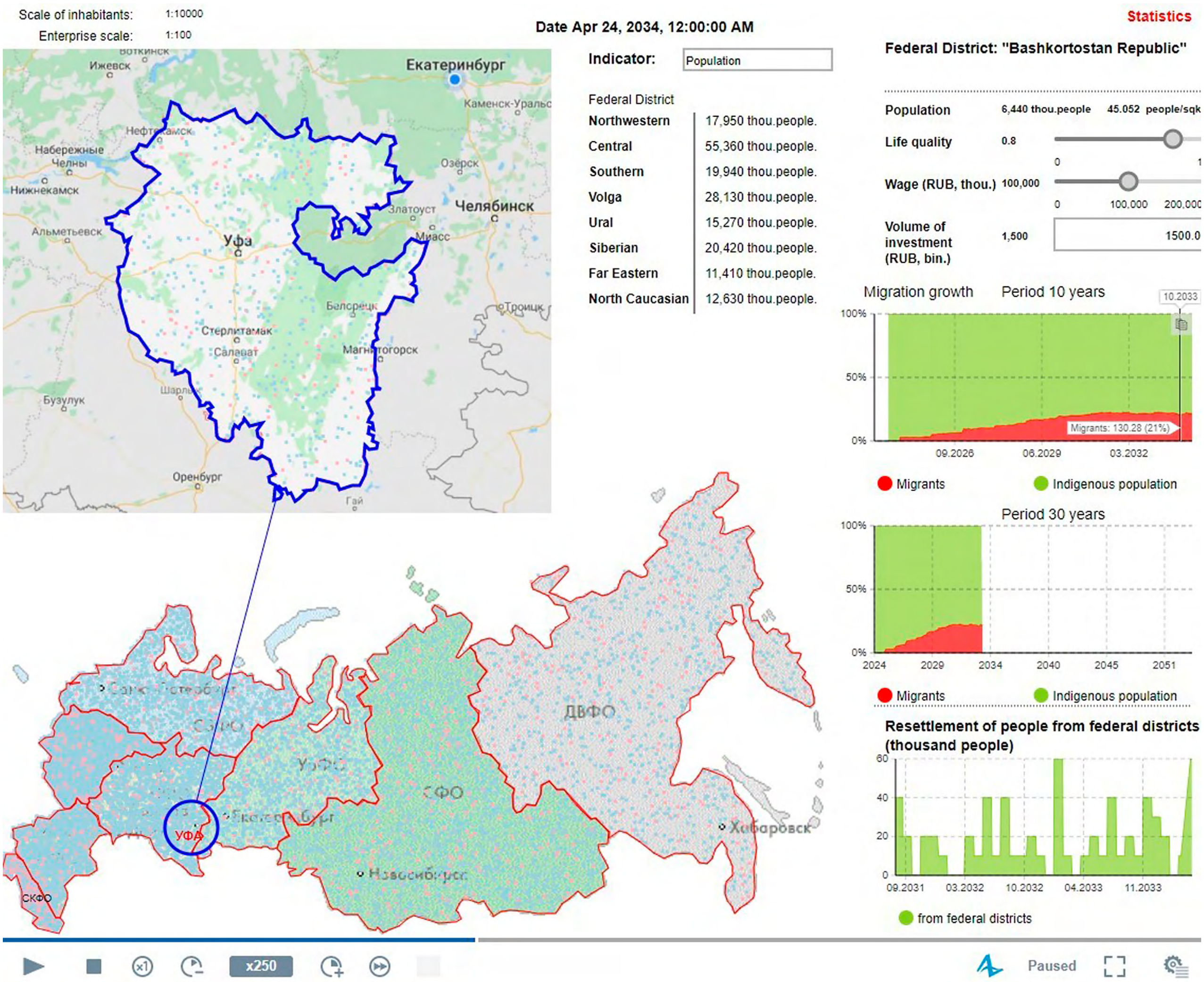

Fig. 5. Interface of the agent-based model for regulating migration flows between federal districts of the Russian Federation.

consideration of the adaptability of their behavior to changes in the operating environment. The integration of IASM into the existing procedures and algorithms of strategic decision-making should be based not on the replacement of the DSS with a model toolkit, but on complementing the capabilities and already available methods. Considering this aspect of the problem under study, it is necessary to briefly describe the stages of strategic planning and the expected place of IASM in these stages (*Fig. 6*). It should be noted that for full-fledged functioning of the IASM within the framework of the DSS, it should be supplemented with a number of functional blocks (data input and output, report generation, calculation of dynamics and structure indicators, etc.), but these issues are not considered in this study, as they are more engineering, rather than scientific in nature.

I. The preliminary stage includes problem definition, organizational support, data collection and pre-

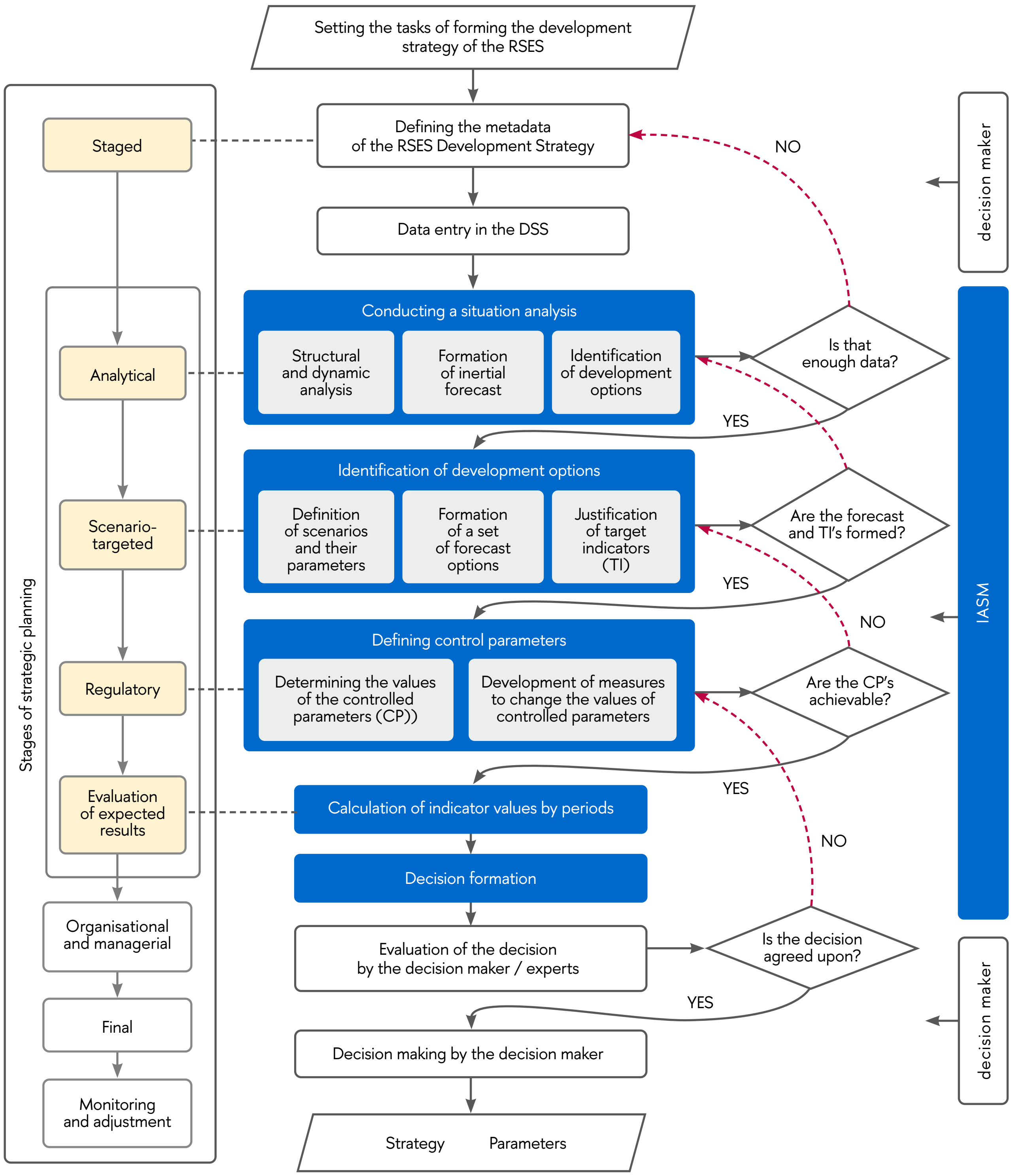

Fig. 6. Algorithm for determining the parameters of the development strategy of the RSES using the IASM-based DSS.

liminary analysis. From the point of view of IASM work, at this stage the data are entered into the system and checked. At the same time, we are talking not only about statistical information reflecting the current situation and development of the territorial system, but also parameters related to the establishment of the planning horizon, exogenously imposed restrictions.

II. The analytical stage includes determining the state and direction of development of the territorial system. Based on the task at hand, it is necessary to assess economic, demographic, social, cultural, natural-geographical and other factors. This stage may involve the implementation of dynamic, structural, SWOT-analysis, the study of individual spheres of society, analysis of advantages, identification of problems and threats to development. The result is the definition of territorial development problems or identification of unused potential.

Integration of the IASM into strategic planning procedures is based on the formation of a conservative version of the forecast of key macroeconomic parameters, implying the preservation of existing conditions and existing values of managed parameters.

III. Scenario-target stage includes the definition of target benchmarks for the development of the territorial system. Within the framework of the IASM, the creation of development scenarios is carried out through the formation of an indicative plan. Thus, the tasks of forecasting and planning the development of the territorial socio-economic system are linked. The application of simulation modeling allows us to take into account the limitations and various conditions.

IV. Regulatory stage. Determination of parameters of the vector of control actions based on the value of target indicators is based on reduction of deviation of current values from those obtained as a result of modeling.

A set of measures is formed to achieve the required values of regulators in the areas. At this stage, the number of required resources is determined.

V. The stage of assessment of expected results. At this stage, the parameters of the territorial system development are determined as a result of multiple revisions of the controlled parameters of all economic agents considered in the framework of modeling. It is this stage that makes the greatest use of the IASM capabilities, because it makes it possible to obtain forecasting and planning estimates first at the level of individual agents and then at the level of aggregated indicators. Parameter estimation is based on a number of modeling experiments.

VI. Organizational and management stage, where the system of strategic decisions implementation is defined. This involves the description of management processes, delineation of authorities and areas of responsibility of executors, methods and mechanisms of interaction, etc. Application of the IASM is not assumed.

VII. Final stage. Before proceeding to the practical implementation of the results obtained from strategic planning, they must be approved in the form of a normative document and receive the appropriate legal status. At this stage, the use of the IASM is also not expected.

VIII. Stage of monitoring and adjustment. During the implementation of strategic decisions, the compliance of the values of the obtained results with the parameters of the indicative plan is monitored. If a deviation is detected, the initial parameters are revised and the modeling complex is adjusted. The frequency of monitoring and appropriate adjustment of the IASM is determined by the objectives of the study and the specifics of the management area.

It follows from the above that the proposed toolkit built on the basis of IASM can be applied at most stages of strategic planning and is an auxiliary tool, not replacing specialists, but improving their efficiency.

On the basis of the developed DS toolkit with the use of agent-based modeling technologies, we obtained a forecast assessment of the dynamics of migration flows between the federal districts of the Russian Federation in case of changes in the value of certain controllable parameters: the integral indicator of the population's quality of life, the volume of investment in fixed capital and average wages provided by the current strate-

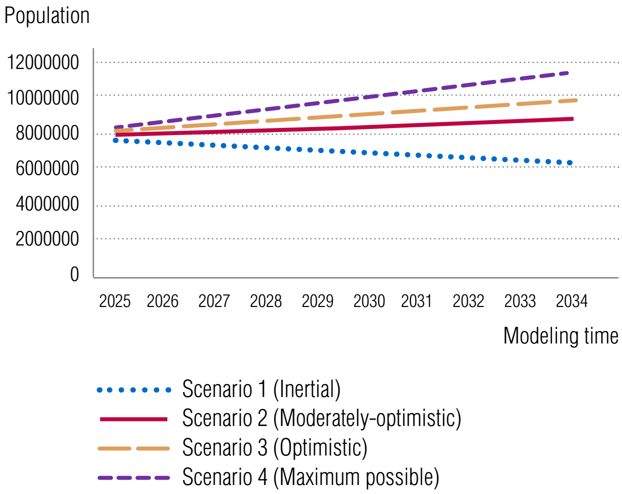

Fig. 7. Model dynamics of population change in the Far Eastern Federal District under different scenario options.

gic plans for the integrated development of territories (*Fig. 7*). Scenario experiments were conducted (using the Far Eastern Federal District as an example of the territory with the lowest population density), which made it possible to forecast for the period up to 2035 the dynamics of the district's population under four basic scenario options, including various combinations of controllable parameters. Preliminary results showed the variation of population change in the FEFD (*Fig. 7*) ranging from –20% (inertial), to +12% (moderately optimistic), +25% (optimistic) and +45% (maximum possible).

In general, the proposed toolkit forms the basis for the development of a balanced demographic and migration policy within the framework of the development and implementation of strategic development plans for the Russian regions in the medium and long term.

Conclusion

The approach to strategic planning of territorial development on the basis of an intellectual model developed in the framework of our research is based on the system integration of various instrumental approaches: methods of agent-based modeling in terms of formalizing the behavior of intelligent agents, which are characterized by adaptive behavior and incomplete rationality; methods of dynamic modeling in terms of formalizing flow data at the macro level.

The proposed IASM structure includes four interrelated hierarchical levels – intelligent agents, macroprocesses, management system and external environment. These levels form the blocks of the model, each of which requires a specific information and methodological basis. In the framework of the conducted research, a model of adaptive behavior of an intelligent agent based on its decision-making has been developed. There is no doubt that each economic agent has distinctive features conditioned by goals, position in the economic system, resources used, significant parameters, etc. The example presented of income generation of the agent "Human" includes only a minor, but important component of the functioning of this agent.

From a practical point of view, the implementation of the IASM-based DSS will increase the level of consistency and efficiency of the decisions taken. In our opinion, such a toolkit may be of interest, first of all, to public administration bodies engaged in the development of strategic decisions at the regional level. An algorithm for determining the parameters of the RSES development strategy with the use of DSS based on IASM is proposed, and the sequence of actions interconnected with the stages of strategic planning is determined. It is shown that most of the key tasks imply the possibility of increasing efficiency through the use of modern information systems. At the same time, the IASM is only a tool, not a substitute for the decision maker. ■

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