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Challenges and Opportunities of Using Simulation Models in Forecasting Socio-economic Development of the Region

Tatjana G. Barkalova[a], Tatjana N. Kokotkina[a] and Evgeny I. Tsaregorodtsev[a]

[a]Mari State University, Yoshkar-Ola, RUSSIA

ABSTRACT

The article is devoted to simulation modeling as a forecasting tool of socio-economic development of the region. It highlights the main advantages and disadvantages of the method, analyses the existing approaches and the constructed models, compares the results and draws conclusions about the applicability of simulation models. On the basis of this study there are assumptions about the future usage of simulation modeling for forecasting of socio-economic development of the region.

KEYWORDS
Forecasting, programming models, econometric software

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Introduction

During crisis and unstable economic development management decisions are characterized by high dynamism, complexity, multi-dimensionality and the presence of overlapping flows of control actions. Clarity, efficiency, completeness, consistency and scientific validity of decisions taken at the regional level is the key to development of the territory. In this regard, the study of socio-economic development of the region becomes especially important.

The region is a complex socio-economic system, which is characterized by a large number of heterogeneous variables and feedbacks, and also combines continuous, discrete and probabilistic processes (Tsaregorodtsev & Sajranova, 2015; Sadovin & Koroleva, 2010; Malykh, Polyanskaya & Lebedev, 2015). Operating such a complex system requires appropriate tools (Kokotkina et al., 2015). Traditional quantitative methods are difficult to apply for describing complex systems and predict their condition in the short and long-term prospect.

CORRESPONDENCE Evgeny I. Tsaregorodtsev ✉ evgts@marsu.ru

Simulation modeling is able to overcome these difficulties (Tsaregorodtsev, 1998). Using this class of models of regional development through a number of sequential computations it is possible to predict the trajectory of the development of the socio-economic system with the specified parameters with different factors and conditions (Mosunova & Tsaregorodtsev, 2006; Kolemaev, 1998). The technology of forecasting activity of the region is based on the concept, according to which forecast is the result of evolution of the initial state of the model region for a specified term, with specified scenario. In the forecasting process the source database is transferred to the prediction point through the model of causal relationships and the exogenous parameters of the model are migrated using a script (Hasaev & Tsibatov, 2002).

This method allows to create models of complex systems describing weakly structured socio-economic processes in conditions of uncertainty with regard to stochastic factors of different nature, as well as to create and evaluate multiple development scenarios of the investigated system or process and to analyze the effectiveness of management decisions and to choose optimum way of development.

Literature Review

Simulation modeling is a very popular method of describing of economic processes, to date, there are many concepts of simulation modeling of various processes and phenomena. “Simulation” usually refers to playback of phenomena, events, actions, objects. Simulation modeling – experimental method of study of the real system by its simulation model, which combines the features of the experimental approach and the specific conditions of the use of computers (Ilyin, 2007; Abakumov, Krylov & Antoshchuk, 2000; Grishin, 2010). In the model the consistency between the parameters is preserved.

The main approaches of simulation modeling include: system dynamics, discrete-event simulation, agent-based modeling (Korovin, 2012; Klochko, Fomenko & Nekrasova, 2016; Timirgaleeva & Grishin, 2013). Also in the researches there are dynamic modeling, unified approach (Zhuravlev, 2009), networks of piecewise-linear aggregates (Lychkina, 2000) and etc. In this study we focus on three main approaches, which are the most widespread.

System dynamics was proposed as the methodology by J. Forrester in 1961 as a research tool for the informative feedback in production and business activities. The aim was to find out the interplay between organizational structure, amplification and delay, the impact they have on the overall efficiency of management. The processes occurring in the real world, in system dynamics are presented from the point of view of drives and transactions between them. System-dynamic model describes the behavior of the system and its structure as a number of interacting positive and negative feedbacks and delays. Systematic approach builds graphical diagrams of causal relationships and global influences of parameters on each other, and then generates a computer model on the basis of these charts. When modeling this way, operations are held not with separate economic objects, but with aggregated elements (aggregated buyer, aggregated service provider). Thus, there is depersonalization of specific subjects, and their behavior is seen as a cost-effective and rational. This assumption often leads to inadequate results of the forecast, as the rationality of decision-making a very controversial issue, conditions can go beyond research, they cannot be predicted.

Forecasting dynamics of the main socio-economic indicators of the region is provided by the availability of partial differential equations, recursive relations and dependencies lag variables obtained by means of econometrics or neuroinformatics (Gafarova, 2013). By using system dynamics it is possible to identify causal relationships and global interdependences of the considered system. This type includes the following software complexes and systems: VenSim, PowerSim, iThink, DYNAMO, Stella, ModelMaker, etc.

The appearance of discrete-event modeling is associated with the name of J. Gordon. In the early 1960-ies, he designed and implemented GPSS system. Using this system it is possible to build a model, represented by series of different states that change instantly for some time. Discrete-event models work with passive transacts or service calls. Transact can be a worker, raw, signal, resource, or other object of economic activity. Moving through the model, transacts form the queue to single-channel and multichannel devices that capture and release them, break down, destroy, etc. (Rvantsov, 2011). This approach of simulation modeling is one of the most common and is used to study the socio-economic, technical, logistic and other processes. Analytical results for a large number of special cases of such modes is considered in queueing theory (Chernysheva, 2010).

In addition to GPSS system, this approach is represented by such systems as Arena, Extend, SimProcess, Enterprise Dynamics, Auto-Mod, etc. It should be noted that the largest number of simulation systems were implemented on the basis of discrete-event approach.

Agent-based modeling is a relatively new stream, taking into account the individual behavior of active objects (agents) and their interactions. Unlike system dynamics, agent-based approach allows to operate not aggregated elements of the system, but a collection of agents with a certain set of properties (e.g., agents-consumers, agents-manufacturers). Agent-based modeling appeared in the 90-ies and is used to study decentralized systems, which dynamics of functioning is defined not by global rules and laws (as in other paradigms of modeling), but when these global rules and laws are the result of individual activity of group members. The purpose of agent models is to gain insight on these global rules, the general behavior of system, proceeding from assumptions of individual, private behavior of its separate active objects and the interaction of these objects in the system. In the case of modeling of economic systems containing large number of active objects (people, cars, businesses or even projects, assets, products, etc.), which combines the elements of individual behavior, agent-based modeling approach is more versatile and powerful, as it allows to take into account any complex structures and its behavior (Korovin, 2012).

Each agent:

— has a set of characteristics;

— has rules of conducting and decision-making;

— has the purpose which influences his conduct;

— is in a certain environment and interacts in it with other agents;

— may have the ability of self-learning based on his own experience.

The most powerful of tools supporting agent-based modeling, is a Russian tool AnyLogic by XJ Technologies company that has proven its power and

flexibility due to applying the object-oriented approach. In addition, it implements a unified approach by providing the possibility of creating hybrid models based on different approaches of simulation modeling (Korovin, 2012).

When modeling socio-economic systems, the most valuable of the methodologies are agent-based and system dynamic. This is due to the different approaches of economic theory. In the greatest development was the neoclassical school of economics that researches the economy with the help of limit values. Such models can be represented as systems of differential equations and therefore correspond to the methodology of system dynamics. Model which was created based on a combination of different approaches will use system dynamics at a high level of abstraction (to describe the behavior of macro-systems), agent-based modeling – at a low level (to describe the behavior of individual economic agents). This can lead to a more accurate reflection of socio-economic dynamics of the region.

Data, Analysis, and Results

The study will consider the most famous Russian and international models of socio-economic development of regions on the basis of system dynamics simulation modeling.

Overview of simulation models of forecasting of development of regions can be started with ready-made solutions that are offered by some companies. Examples of such decisions are the simulator "Dream Valley" (2015) (IIASA), program-instrumental complex "Prognoz" (Gafarova, 2013). Another well-known analog of implementation of this approach is the territorial automated system "TAIS" (Rvantsov, 2011), developed by scientists of the Samara state economic academy. Also it's worth to note the system for analysis and modeling of the dynamics of the regional budget "the Governor" developed in the scientific center of the company "Franklin&Grant. Risk Consulting" (Lychkina, 2013).

Table 1. Turnkey solutions for forecasting of socio-economic development of the region

Model name	*Developer*	*The structure of the model*	*Advantages*	*Disadvantages*
Dream Valley	International Institute for applied systems analysis (IIASA), The Republic Of Korea	Economic agents: people, 27 economic sectors, the government	Representation of the dynamics of the region under the influence of internal and external shocks; testing the potential effects of various policies pursued by the government.	No possibility of forecasting economic and demographic situation in the future.
«Prognoz»	CJSC "Prognoz". Andrianov D.L., Russia	Unit of scenario conditions, 4 unit parameters (production, population, employment, finances), the unit of comprehensive assessment of the	Forecasting of territorial development; implementation of scenario calculations; possibility of solving inverse problems.	Complexity of information security; weak balance and the accuracy of the prediction results.

		development of the regions		
«Governator»	JSC Franklin & Grant. Risk consulting", Russia	4 subsystems: scenario modeling, assessment of the regional economy, evaluation of budget performance, cognitive modeling	Use of a modular system; ability to track and adjust the progress of the simulation; high flexibility; use of several types of modeling.	High cost; narrow specialization; complicated adaptation for a specific region; use of a number of statistical indicators that are not tracked by official statistics.

This software is designed for monitoring, analysis and forecasting of regional development. Such universal instruments, as a rule, constitute a system of dependencies, describing the state of the economy for the short and medium term. In the simulation calculations of the studied socio-economic and production processes are described in the form of difference ratios, economic-mathematical model reflecting dynamics of development of these processes. Mathematical description of the model is developed on the basis of using the existing economic-mathematical methods in combination with intuitive modeling and is implemented in the form of a computer program, which conducts experiments by feeding the input of external influences in the form of specifying the values of the input variables and calculating output parameters. Scenarios calculations are formed by specifying the values of input parameters. An additional problem of simulation experiments is providing the necessary adequacy of the developed models to the real objects.

Mathematical models used for prediction, can be adjusted for the specifics of each simulated region and its statistics. Predictions on the basis of such universal models are usually made on statistics for 5-7 years. This short retrospective analysis, in our view, is not conducive to reliable forecasting. Besides, the lack of specialists in economical mathematical modeling among the users of such systems does not allow proper tuning of the model to the specifics of the region (and it is not always possible). All the above leads to the fact that regional predictions based on such models becomes formal.

The next set of models are models tailored to a specific region. Among such models it is possible to point out simulation models from different countries. Linear dynamic simulation model ABPPS simulates the economic performance and the choice of optimal management strategy for livestock industries. There are such models as the models of the U.S. agricultural sector AGMOD and SWOPSIM and developed by Canadian economists production model KPC ABPPS (Alberta Beef Productions System Simulation System). Linear dynamic model of the agricultural sector of Finland, DREMFIA (Lehtonen et al., 2007) performs economical mathematical analysis of structural changes in the agricultural sector of Finland, simulation of perspective volumes of production of the agricultural sector of Finland in the medium term. The model of the agricultural sector of France MAGALI (Ministry of agriculture of France,

National institute of agricultural research of France) builds a simulation of the impact of the decisions for the development of the agrarian sphere of agricultural territories, the dynamics of prices on agricultural production, rural employment, cost of factors of production.

Next, we consider only those models that take into account the specifics of a particular region. Let's begin with the models using system dynamics approach.

Such models include modeling complex "SIRENA-2 (Synthesis of regional and national economic decisions), territorial automated system of TAIS and analysis system ”Modeling of socio-economic development of the region, the forecasting system in the region” by Institute of informatics and mathematical modeling of technological processes Russian Academy Science, model of the Kirov region, built by a computing center named after A. A. Doronitsyn, and integrated model for medium-term strategies for socio-economic development of the region.

Table 2. System dynamics simulation models of regional development

Model name	*Developer*	*The structure of the model*	*Advantages*	*Disadvantages*
Linear dynamic model of the agricultural sector of Finland	DREMFIA (Lehtonen et al., 2007)	The Central core block of optimization, modeling competitive markets The optimization problem of simulating market changes is calculated annually	Allows to simulate the dynamics of the production of agricultural products in the medium term	Narrow specialization
Territorial automated system (TAIS)	Samara state economic academy	Economic agents: entities of the sector of goods production and market services; entities of the sector of nonmarket services; households; regional lead; Federal lead; the external environment.	Balance of forecasts; Possibility of accounting expertise; Forecasting in sectoral and territorial breakdown.	Limited use of techniques of scenario analysis
Model complex "SIRENA-2 (Synthesis of regional economic solutions)	Institute of Economics and industrial engineering SB RAS	The structure of regional subsystem: manpower and population; capital investments; local resources (land, water); transport; inter-regional relations; social factors	Conduction of interregional comparisons Possibility of identifying trends in the development of several regions Consistency Practical orientation Possibility of modification	The lack of personification of the subjects of the implementation of the decisions

Analytical system "Modeling of socio-economic development of the region"	State university of management	Subsystem: population; production; non-production sphere; external economic sphere; space; finance; ecology	Ability to analyze disparities of regional development. Social orientation of the model: the development of health, education and housing. Detailing the resource potential of the region's natural resources	The lack of consideration of innovative component
Model of the Kirov region	The computing center named after A.A. Doronicyn,	Components: manpower; mining (energy); processing industry (fish industry complex).	Examines shadow production and shadow wages.	The lack of consideration of innovative component

All models given in the table allow to build long-term and short-term forecasts of the main socio-economic and financial indicators in the region, to create and to research different strategies of regional development.

Moreover, model complex SIRENA-2 is multi-regional and allows to hold inter-regional comparisons to identify trends in the development of several regions. A significant drawback of all the models is the disregard for the modeling of innovations.

Regional models mentioned in the table vary in different economic and mathematical tools underlying the simulation (differential-integral equations, neural networks, econometric equations, etc.), ensuring the balance between supply and demand on the markets.

Finally, let's consider agent-based models of regional development. Such models are presented in Table 3. The number of such models is much smaller, they are not as common as system dynamics models. All the models are characterized by a low level of abstraction as agents allocated to both individuals and enterprises, sectors of the economy. Economic agents can relate to a specific area and to the entire region (the agents responsible for the functions of the state). Some interactions can occur within the same district, and some are between agents from different areas.

Agents can include system dynamic diagrams, algorithmic rules of behavior, variables, state diagrams. Model created using the presented methodology is able to predict the development of socio-economic system in different conditions, to determine the most preferable management strategy. It is possible to conduct experiments to determine the optimal values of some parameters that maximize the target function

The model can be used to support decision-making at various levels of regional management. Decomposition of the model for separate districts and the

economic agents allows to use it also in management tasks on municipal and district level (Tsaregorodtsev, Semagin & Mosunova, 2009; Kokotkina et al., 2015).

Finishing the review of simulation models, it's necessary to note that the creation of models of "first generation" demanded that researchers first of all develop tools that allow to create architecture models and to perform calculations on it.

We also should identify emerging libraries for simulation modeling. Among them we should note the software library Aivika (Sorokin, 2015). Basic and generalized versions of the Aivika library are focused mainly on discrete-event simulation, and it also has the support of system dynamics and agent-based modeling. The generalized version is adapted for the nested simulation and the distributed parallel simulation (optimistic strategy with a transparent kickbacks is implemented). Aivika allows specialists to operate events, discrete processes, resources, queues, servers, streams transaction and their handlers on the level of Haskell programming language. It simultaneously allows to determine the events and processes, delving into low-level details of the behavior of the simulated entities, and create high-level network of queues in a declarative way.

In conclusion, it should be noted that the development of agent-based and system dynamic modeling and software in the field of simulation modeling open up for scientists the great prospects for further development of the regional modeling.

Table 3. Agent models of regional development

Model name	*Developer*	*The structure of the model*	*Advantages*	*Disadvantages*
Model of a region in the Russian North (Korovin 2012)	Syktyvkar state university	Levels: economic agents; district, region. Agents: people; company; bank; owner; district; state.	It is possible to conduct experiments to determine the optimal values of some parameters that maximize the target function; Decomposition of the model for separate districts and the economic agents allows to use it also in management tasks on municipal and district level.	The lack of consideration of innovative component and the informal sector
Agent-oriented regional model "Gubernator"	Central economics and mathematics institute of RAS	Agents: individuals; legal entities; municipal areas.	Consideration of the human factor Modeling individual behavior of agents - "individuals": birth, college enrollment, employment, change of activity, change of residence, change of attitude to work, death.	Has some limitations (for example, presupposes the complete absence of unemployment) and requires further development.
The agent-based model of Mosco	Central economics and mathematics Institut	Agents: people; companies. Environment of the model: areas; roads; public transport	The calculation of the main socio-economic indicators of development of Moscow city (population, gross regional product, unemployment rate, per capita income),	Narrow specialization

w city	e of RAS	(metro)

Discussion and Conclusion

When modeling socio-economic systems the most valuable methodology - agent-based and system dynamics. This is due to the different approaches of economic theory. In the greatest development was the neoclassical school of economics that researches the economy with the help of limit values. Such models can be represented as systems of differential equations and therefore correspond to the methodology of system dynamics.

Another approach to the study of economics – behavioral economics. It is based on the premise of bounded rationality, namely that economic agents do not always abide by the maximum rational behavior, and stops on one of the relatively acceptable. Then the behavior of this entity can be described algorithmically. For simulation of such processes agent-based methodology is used.

Key advantages of simulation modeling are the following:

— ability to describe complex systems characterized by many nonlinear relationships and large number of heterogeneous variables;

— simulation of behavioral aspects and dynamic processes of the environment;

— ability to identify patterns, dynamic development trends and operation of complex system in conditions of incomplete and inaccurate information;

— description of the interaction and behavior of many active agents in social systems;

— implementation of the principles of object-oriented design and the use of high-tech solutions in the construction of computer models, etc. (Lychkina, 2013).

— using modular structure for building an information system based on them, this approach allows the most efficient use of hardware resources, shortening processing time.

— tracking the indicators on each stage of the simulation.

It is obvious that simulation models also have some drawbacks. First of all, it is worth noting the high cost of the development of the simulation model. So, creating a model at the regional level requires the involvement of not one expert, but of the entire team. Building such models also take much time. From the point of view of the implementation of the simulation results we should note the need for financial and informational support and training of staff of public authorities of the region. There is also the difficulty with the collection of initial data for the simulation model. They are not always collected and analyzed by Federal state statistics service. This can significantly reduce the adequacy of the model.

Thus, the model based on the combination of different approaches will use system dynamics at a high level of abstraction (to describe the behavior of macro-systems), agent-based modeling – at a low level (to describe the behavior of individual economic agents). This could lead to a more accurate reflection of socio-economic dynamics of the region.

Using the models allows to understand the internal logic of development of economic processes. Experience with the usage of such models showed that they

are a reliable tool for the analysis of macroeconomic regularities and forecasting of consequences of macroeconomic decisions while maintaining existing relations (Korovin, 2012).

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Notes on contributors

Tatjana G. Barkalova, Department of Economics and Finance, Mari State University, Yoshkar-Ola, Russia.

Tatjana N. Kokotkina, Department of applied statistics and Informatics, Mari State University, Yoshkar-Ola, Russia.

Evgeny I. Tsaregorodtsev, Department of Economics and Finance, Mari State University, Yoshkar-Ola, Russia.

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