

MULTI-AGENT MODEL "GOVERNOR" FOR A COMPUTER SIMULATION OF THE REGION AS A COMPLEX SOCIO-ECONOMIC SYSTEM

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JEL Classification: C 63; D 01; E 47; H 30; H 40;

Review

Received: December 15, 2012

Accepted: February 23, 2013

Abstract

This paper describes the agent-based (multi-agent) model. Model simulates the socio-economic condition of the region based on the reconstruction of its internal structure, as well as the structure and behavior in its territory of autonomous economic agents. An multi-agent model is an artificial society of interacting autonomous agents, each of them having a given set of personal characteristics ("resources") which define its value in the model in terms of its intended role in social production, an objective function (the "interests") and is subject to the specified rules of conduct. The model contains agents that correspond to the basic of economic actors forming the following hierarchy: agent-people → agents-organizations, in which people work, → agents-municipal districts, on the territory of which organizations are located and people live, → the region-constituent entity of the Russian Federation, which includes municipal districts. Aggregation of individual characteristics makes it possible to estimate the overall "usefulness" of each agent, in which the agents-people model corresponds to their labor potential, and for the following levels of agents is a function of the total labor potential of the agents-people included. The budgets incomes consist of tax liabilities of agents-enterprises of the real sector and individual income tax of agents-people. Further on, the funds supplied to the budget are distributed among public administration, education, public health service, science and culture. Therefore, the activity of agents-people of working age, who fulfill their employment potential, serve as the foundation of the overall economic life of the region in the model. The model is implemented in the form of a custom software product and it is set up to test different management strategies for income and expenditure of the budgets of two levels: the regional budget and the budgets of municipal districts.

Key words: *agent-based modeling, testing of the regional policy, the structure of personality, human behavior in socio-economic environment, the labor potential*

The objective of this work is to create a fairly realistic computer model of a constituent entity of the Russian Federation (the region), designed to test different variants of governing actions based on a simulation of the region functioning as a complex socio-economic system. The main outstanding feature of major economic actors such as regions is that they represent large socio-economic systems with a complex hierarchy of smaller economic actors included in them – starting from local residents of the region and organizations within its territory to its constituent municipal formations. Thus, the regions are active systems (Burkov, 1989), as these smaller economic actors are independent in the region - they have their own resources and act in their own interests, within the limits of generally accepted rules.

Recently, a special kind of simulation technique - namely, agent-based simulation - is increasingly being used to model these active systems (Makarov, 2007; Bahtizin, 2008; Handbook of Research on Agent-Based Societies..., 2009). An agent-based (multi-agent) model is an artifi-

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cial society of interacting autonomous agents, each of them having a given set of personal characteristics ("resources"), an objective function (the "interests") and is subject to the rules of conduct predetermining its reaction in various situations involving its area of interest. An important feature of multi-agent models is that specific values of the characteristics of agents may differ. It is this feature which allows using the multi-agent models to reconstruct the internal structure of large socio-economic systems, in which society does not consist of some average "typical representatives", but of a variety of many different types of actors who also have some individual differences. Considering the fact that simulations allow us to observe the processes occurring in the simulated objects in real time, the advantages of such models become obvious, as a tool to test different variants of control actions and analyze their impact.

The model created in the region contains agents that correspond to the above-mentioned basic types of economic actors forming the following hierarchy: 1) agents-people → 2) agents-organizations, in which people work, → 3) agents-municipal districts, on the territory of which organizations are located and people live, → 4) the region-constituent entity of the Russian Federation, which includes municipal districts.

Each type of agent has a certain set of characteristics which define its value in the model in terms of its intended role in social production, some of these characteristics remain constant, and part of them vary with time and / or due to any processes taking place in the model. Aggregation of these individual characteristics makes it possible to estimate the overall "usefulness" of each agent, in which the agents-people model corresponds to their labor potential, and for the following levels of agents is a function of the total labor potential of the agents-people included. Therefore, the activity of agents-people of working age, who fulfill their employment potential, serve as the foundation of the overall economic life of the region in the model.

In addition, each type of agents has a "system of values" (preferences) and is able to estimate the available information about the characteristics of his environment and his position in it, based on which the activity of agents is simulated, as well as their "behavior" as a purposeful change of their characteristics in order to maximize their usefulness. At each step of the model operation (one step corresponds to one year in real life), the agents engaged in production analyze the available information about the characteristics of the environment and their own position in it, and in accordance with their value system pass into a particular state: "normal" (start), "resentment" and "critical" (when urgent actions are required). If the state of an agent is different from normal, it prompts him to react, and this reaction will depend not only on the condition and the values of other characteristics of the agent, but also on the opportunities provided by the environment. Thus, the behavior of agents is a function of their personality structure and the environment characteristics, for which the agents-people conform to the theory of personality by R. Cattell (Holl, and Gardner, 2008). Moreover, the behavioral sequence of the agents implemented in the model is based on the behavioral act structure of functional systems theory by physiologist P. K. Anokhin (Sudakov, 1990), comprising the following steps: identifying a situation of interaction with the environment as requiring some actions; goal-setting of acting and forming its program, implementation of actions and evaluation of the achieved results.

The role of the external environment for the agents is played by the higher-level agents of the hierarchy (one level agents in the model are not in direct contact with each other). Thus, for the agents-people these are agents-organizations, agents-municipal districts and the region as a whole, that is, in accordance with generally accepted terminology (Bloomquist, 2006), the described model belongs to the class of agent-based models of Social Norm Promotion with n Influential Groups (SNPⁿ), where $n=3$.

A separate task is the development of algorithms that allow connecting the labor potential of agents and the real impact of their work. It is obvious that one needs to use some analogues of production functions as a dependency of the agents' work results on their disposable resources. However, it would be wrong to consider the real contribution of agents in social production as depending only on their internal capabilities; one must also consider the agents' environment. Therefore, the external environment also fulfills the restrictive function in the model, on the one

hand, setting the conditions necessary for the agents' capacities implementation, on the other hand, simulating the demand for "products" they've manufactured. In this case, the concept of "products" is defined by the role predetermined for a particular agent in the model.

For various types of agents, the internal factors and external conditions that determine the success of their operation are listed below, and the internal criteria for success (value system of agents), as well as the predetermined functions for agents in the model and indicators of their activities estimate are described.

Agents-people

Factors: health, abilities, creativity, education, work experience, diligence and temperament (determines agent features such as activity, reaction rate and ability to adapt to the changing conditions of external environment (Симонов, 1983)). Thus, agents-people are endowed with "personality," the structure of which, in essence, is formed by the so-called "original features" of the factor theory of personality by R. Cattell, corresponding to "... the real unitary forces - physiological, temperamental factors, the degrees of dynamic integration, openness to social institutions..." (Holl, Gartner, 2008).

The agent's integral characteristic is **Labor potential**.

The system of values: the priority of the basic life aspirations and relevant criteria for estimate of satisfaction with their position. The model includes such criteria as income level, confidence in the future (stability), career growth and self-actualization; and the system of values is an array of four numbers, each determining the importance (weight) of the relevant criteria (in total, weights amount to one).

Environment conditions:

a) *Depending on the place of residence* - workplace, tax burden, infrastructure, public health service and education systems. Work of the public health service system in the model affects the state of health of the population, which is a part of the labor potential, and the education system provides the required level of employees' qualification, that is, also affects their labor potential value. Demand determines the availability of work positions in the labor market.

b) *Depending on the place of work* - based on the concept of organizational culture as a set of goals and relevant criteria of activities effectiveness, specific for each organization, as well as the key factors determining this performance (Kameron, 2001). Organizational culture determines the demand for such features of the agent as activity and creativity - if the agent has these properties, and they are in demand, then the results of his labor and wages increase. Thus, most agents can only realize their potential with an appropriate organizational culture profile.

Behavior. Self-changing characteristics of the agent: entry to educational institution, relocation, change / choice of employment, change of zeal for his work (Susko, 2012). So, if a dissatisfied agent cannot improve his position, then his zeal for work decreases (Делавинья, 2011b, p. 61) and, consequently, - his labor potential also decreases.

Agents-organizations.

Agents of the second level of the hierarchy (agents-organizations) in the model are the branches (activities) within the municipal district. Agents-organizations are divided into two categories:

1) Agents-enterprises of the real sector, that is, companies that manufacture products - industry and agriculture, as well as service enterprises, referred to the infrastructure. Products manufactured by these companies can be delivered both to municipal and regional markets, and can be exported outside the region, respectively, the demand for products is divided too.

2) Agents-organizations of the social sphere - education and public health service systems, as well as science and public administration. The quality of performing their functions by these systems is estimated by the degree to which financing standards are met in comparison to the base year.

Factors: the total labor potential of the employees, the available financial means.

The system of values:

a) *Directed to the internal environment* - specific work potential and the level of employees satisfaction.

b) *Directed to the external environment* - production output, labor productivity, the number of jobs.

Environment conditions:

a) *Regional* - natural population movement (mortality, fertility), tax burden (for the real sector enterprises); funds allocated from the budget; demand for products.

a) *Depending on the municipal district where the organization is located* - human resources, infrastructure, demand for products.

Behavior. Change of activity results.

Agents-municipal formations.

Agents of the third level - municipal formations - are in some way the social and industrial complexes, including second level agents each performing a specific economic and social function.

Factors: total labor potential of the employees, results of activities of organizations, available financial means.

The system of values:

a) *Directed to the internal environment* - specific work potential and the level of employees' satisfaction.

b) *Directed to the external environment* - production output, quality of life of the population.

Environment conditions. *Regional* - natural population movement (mortality, fertility), tax burden (for the real sector enterprises); the share of tax liabilities of the real sector enterprises that can be left in the budget of the municipal district; monetary assets received in the form of subsidies from regional funds. There are no restrictions on the results of activities in the form of "demand."

Behavior. Change of activity results.

The model is implemented on the example of Vologda region in the form of a custom software product developed in the environment of AnyLogic (XJ Technologies) and called "Agent-based Regional Model (ARM) Governor".

In order to provide relevant modeling of the labor potential of the region, its development and usage, as well as to make the operating mode comfortable for the user during the conduct of computer experiments, the "Governor" model includes the following blocks:

- The block of setting the initial state of the system corresponding to the actual data on socio-economic characteristics of the region in a selected base year,
- The model of formation and usage of the budget,
- The model of prediction of demographic situation in the region and its individual municipal districts,
- The model of labor potential of one human agent and his conduct as an employee,
- The model of labor market and employment pattern,
- Production model, and
- The block of results visualization and interaction with the user.

Data on the state of the Vologda Region in the base year (selected as year 2004) and subsequent years, represented in the collected documents of Rosstat were used to calibrate the model. In addition, we used the data obtained during the research conducted by the Vologda Institute for socio-economic development of territories of RAS (Amelin, 2006). The model is calibrated in a way that the statistical data calculated from a range of agents should coincide with the real official statistical data on the population size of each municipal district and its sex and age composition, as well as the employment pattern by types of activities, sex, age and educational level of employees, with the corresponding differentiation of wages.

The model is set up to test different management strategies for income and expenditure of the budgets of two levels: the regional budget and the budgets of municipal districts, having certain assumptions about development of the overall economic situation in the country. The consolidated budget of the region is formed in the model with a selection of budgets from municipal districts within the region. The Budgets incomes consist of tax liabilities of agents-enterprises of the real sector and individual income tax - as a share of payroll of agents-people engaged in all types of activities. Tax liabilities rates as a share of production output, as well as a ratio of tax liabilities distribution among the budgets of two levels are set separately for each type of activity. In addition, due to the part of tax liabilities, two regional funds are formed, as a means to equalize the fiscal capacity of various municipal formations: the "Regional Financial Support Fund for Municipal Districts (urban districts)", and the "Regional Compensation Fund." Procedures of formation and distribution of means of these funds among municipal formations of the region in the model comply with the existing legislation in the field of inter-budget relations.

Further on, the funds supplied to the budget are distributed among such types of activities as public administration, education, public health service, science and culture. In the model, these areas are fully financed from the budget in accordance with standards of budget expenditures, as follows:

- Public administration - given proportion of the budget, %,
- Public health service - annual expenses per capita, thousand rubles,
- Education - annual expenses for one student, thousand rubles, and
- Science, Culture - given proportion of the budget, %.

The remaining means of the municipal districts' budgets are directed to "Infrastructure," and the means of a regional budget, in addition, may be invested in other types of activities of the real sector.

The only automats in the model are agents of the first level - people, and change in characteristics of other types of agents should be available to expert users to simulate a variety of options for control actions. Hence the choice of variable parameters in the process of model operation:

1. The level of the region as a whole:

- The share in production output of the real sector branches (donor branches), transferred to the region budget as tax liabilities, %.
 - The share in tax liabilities of donor branches left in the budgets of municipal districts, %.
 - Standards of budget expenditures for public administration, public health service, education, science, Rub.
 - Amounts of budget expenditures for maintenance of industry, agriculture, infrastructure, million rubles.
 - Fertility rate.
 - Mortality rate.
-

2. The level of municipal district:

- Disposition of budget funds between items of expenditure, million rubles.

3. The level of organization:

- Projected number of employees, pers.
- Projected level of wages, rubles.
- Projected production outputs for the real sector organizations, million rubles.
- Organizational culture characteristics: stability marker, career growth rate and demand indicator for creative capacities of employees.

Using the "Governor" model, numerical experiments were conducted to simulate the population dynamics in the Vologda Region, its municipal districts and enterprises on their territory having different values of model controlled parameters.

Experiment 1. Managing distribution of the consolidated budget income among the budgets of two levels - the budget of the Vologda Region and the budgets of its municipal districts.

This problem is extremely urgent for Russia, because in our country, obviously due to the high level of management centralization and accumulation of financial resources in the center, the budgets of the majority (!) of municipal formations are subsidized. At present, variants of reforming this sector are being discussed to ensure the greater independence of municipal formations, including financial independence.

Variable parameters are the share of tax revenues collected in the municipal districts and remaining in their budget. In the experiment, the total tax burden on enterprises of different branches, as well as on working residents of the region does not increase, but funds coming in the form of tax are distributed differently among the budgets of the two levels.

The first (base) variant corresponds to actual distribution of the consolidated budget of the region in 2004. In the second variant, 50% of individual income tax comes to the budget of municipal districts. The third variant increases the share of the municipal districts' budgets to 60% (up to the level required for agriculture) in all the collected taxes, except for the tax on production output of major industrial enterprises, the share of which is left unchanged at 20% (Table 1).

Table 1

Code	Tax base	Share of tax liabilities remaining in the budgets of municipal districts, %		
		Variant 1	Variant 2	Variant 3
1	Production output of major industrial enterprises	20	20	20
2	Production output of small and medium-sized industrial enterprises	30	30	60
3	Agricultural production output	60	60	60
4	Service-producing industries turnover	50	50	60
5	Employee wages	30	50	60

The objective of the experiment was to trace the influence of tax revenues redistribution on characteristics of municipal districts, such as self-sufficiency of their budgets (share of own incomes), and the fiscal capacity per capita (final, that is, after the subsidies distribution). The results are shown in Table 2.

The data in Table 2 show that although the average size of the budget of the municipal districts accounted per capita increases in the second and third variant (by 10.1% and 26.5% respectively), but at the same time, the regions differentiation by this index increases. In addition, in the latest version, the regional budget turns out to be adverse, that is, it is not possible to

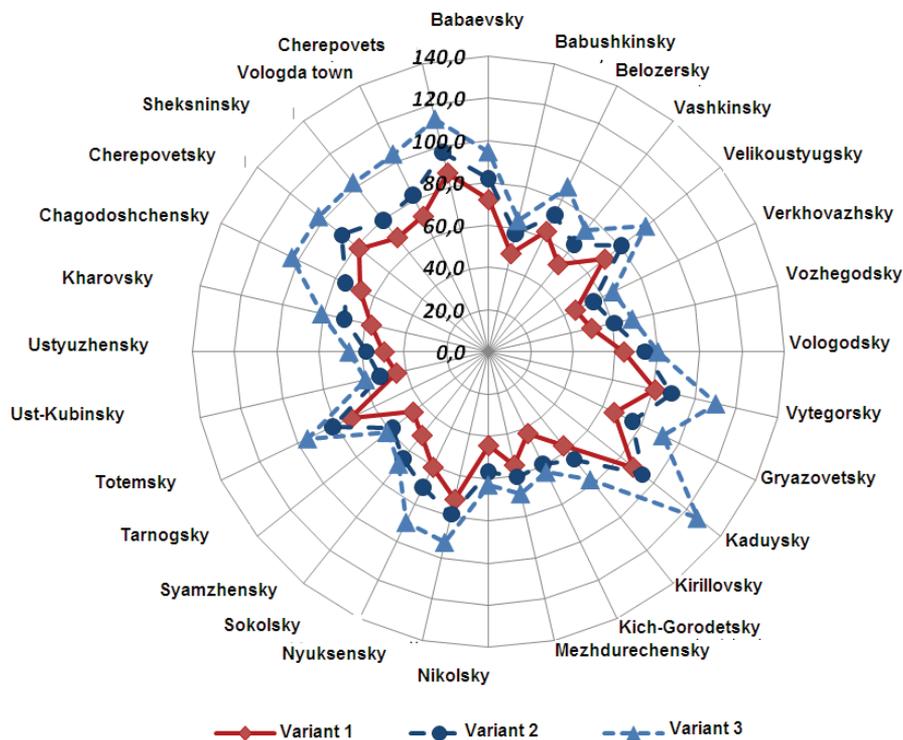
maintain the regional budget investments in industry and agriculture at a given (actual) level at their own expense, as was provided in the first two variants.

Table 2

	Variant 1	Variant 2	Variant 3
<i>Fiscal capacity per capita, conventional units</i>			
<i>Medium</i>	11.02	12.13	13.94
<i>Minimal</i>	8.0	8.9	9.7
<i>Maximal</i>	14.3	15.2	19.9
<i>Self-sufficiency of budgets, %</i>			
<i>Medium</i>	61.6	65.1	67.5
<i>Minimal</i>	42.8	48.2	49.6
<i>Maximal</i>	87.4	88.1	91.0

With regard to the criterion of self-sufficiency of budgets, the reviewed variants differ both by income and by expenditures of the district budgets (due to the redistribution of regional funds). It would be more evident to compare different variants of income, assuming that costs remain at the level of the first variant of tax revenues distribution. The relevant comparison is shown in Fig. 1, where one can see that in the third variant, incomes of seven municipal formations exceed expenditures of the base variant (self-sufficiency of the budgets is more than 100%), and budget incomes of other five districts almost cover the expenditures (self-sufficiency is over 90%). However, even such redistribution of tax revenues does not allow for most municipal districts to do without subsidies.

Fig. 1: Comparison of self-sufficiency of expenditures of Variant 1 at different variants of income.



Experiment 2. Managing budget expenditures on public health service. Urbanization, environment degradation, along with the noticeable trend of an aging population, typical of modern Russia, have a negative impact on the population's state of health and objectively require an inc-

rease of expenditures for public health service. On the other hand, the budget is limited, including other State social obligations. Therefore, there is definitely an urgent problem to find an acceptable compromise, that is, a level of funding this branch, which would allow maintaining the population's working capacity.

Variable parameter is a standard of budget expenditures on public health service per capita in the region. State of health of agents-residents (*Health*) in the model can take on a value "poor" "normal" and "excellent" (1, 2, 3). Moreover, the initially set point for agents older than nineteen years of age can decrease with age increment (*Age*), as well as with reducing the norm of budget expenditures on public health services. In the experiment, it is considered that these factors contribute equally to the probability of decline of agent *p*, calculated according to the following formula:

$$p = 0.011 * (Age - 20) + 0.5 * (1 - NormHealth / BegNormHealth),$$

where *NormHealth* is a standard of budget expenditures on public health service in this year, and
BegNormHealth is the same standard in base year 2004.

The objective of the experiment was to trace the effect of reducing the budgetary expenditures standard on such integral characteristics of the region as a proportion of apparently healthy residents among the employed population (*Health* > 1), as well as specific labor potential. For this, scenario calculations were made within the period from 2004 to 2008 with the following variants of social policy:

- Variant 1 (Basic) – the standard remained the same throughout the whole period;
- Variant 2 – the standard was reduced by 5% in 2005 and remained at the same level in the ensuing years
- Variant 3 – the standard, same as in the second variant, was reduced once in 2005 by 11%.

The obtained results are compared in Table 3.

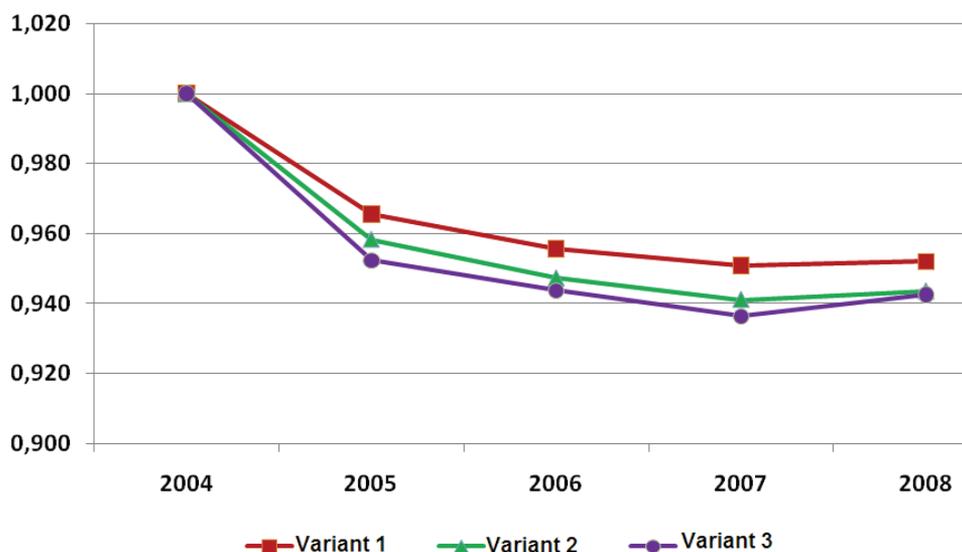
Table 3

	2005	2006	2007	2008
<i>Proportion of apparently healthy agents, %</i>				
<i>Variant 1</i>	71.2	70.1	69.8	70.2
<i>Variant 2</i>	69.6	69.4	68.6	68.8
<i>Variant 3</i>	66.0	66.7	66.9	67.0
<i>Specific labor potential of agents</i>				
<i>Variant 1</i>	0.392	0.388	0.386	0.3865
<i>Variant 2</i>	0.39	0.3855	0.383	0.384
<i>Variant 3</i>	0.389	0.3855	0.3825	0.385

In this experiment, it is assumed that the standards are set in the base year prices. Therefore, the standard reduction in the second and third variants can be considered as an imitation of inflation, and the third variant corresponds approximately to the level of inflation in 2005.

As one can see from Table 3 data, the proportion of apparently healthy employees decreased in each subsequent variant, that is, reduction of public health service financing in the model leads to deterioration in health state of the population. As the health indicator is a constituent part of the labor potential of agents, thus, the average value of the labor potential should decrease with their health deterioration. In Table 3 the specific potential varies slightly for different variants, however, a comparison of the indices behavior of this indicator regarding the initial point value (Fig. 2) shows the impact of financing public health service on agents' work capacity.

Fig. 2. Comparison of index dynamics of the specific labor potential



Conclusions

In conclusion, we would like to emphasize that the developed multi-agent model is an attempt to create a tool to test regional management mechanisms taking into account the human factor. Here are the main features of the model that make it such a tool:

First and foremost, it is modeling the structure of the region as a complex hierarchical system consisting of independent economic agents of different levels, with the region residents as the basis.

Secondly, it is modeling the structure of personality and behavior of individual agents with regard to their differentiation, which allows tracking various impacts of management actions on individual agents or groups of such agents. The society is stratified, and it can appear to be important for predicting its response to changing economic situation and / or the rules of the game set from above. This correlates with behavioral economics approach (Kaneman, 2003; Delavin'ja, 2011a-c, and, according to Delavinya, "we need to make greater use of the ideas of behavioral economics in public policy" (Delavin'ja, 2011c, p. 106).

Thirdly, it is building the chains of dependencies, allowing to simulate also the response influence of the status and employment of agents-people on economic and social indicators in the region, such as, for example, specific work potential of employees, the proportion of residents who are healthy and satisfied with life. The model takes into account such effects by using various procedures of aggregation of characteristics of the lower level agents in order to obtain the features of agents of the following levels.

Therefore, the chains of influence of user actions on the output parameters of the model are made using the procedures of calculating the parameters of the budgets of two levels, the procedures for determining the states of agents-residents of the region, and their behavior modeling as employees, as well as mechanisms for the subsequent aggregation of their labor potentials. In particular, the model design is intended to demonstrate visually the dependence of the region integral parameters of budget expenditures on social services as an investment in human capital. In fact, this approach allows modeling the cause-and-effect relations underlying the construction of a balanced scorecard (BSC or "Balanced Score Card" (Kaplan, and Norton, 2003, p. 304). Although BSC was developed by D. Norton and R. Kaplan for managing the sustainable development of corporations, but in recent years, this approach is also used for managing the development of territories, for example, when designing a system for monitoring the implementation of strategy of socio-economic development of the region (Susko, 2010, p. 139).

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