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Simulation Model of The Demographic Situation of The Volga Federal District

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***Abstract*—The demographic development of a region is the basis for the formation of labor resources. This study describes an algorithm for developing a simulation model of a region's labor potential. The article shows the analysis and socio-economic factors affecting the demographic condition of the Volga Federal District. The modeling of the main demographic processes was carried out with the inclusion of multiplicative correction factors. The model is implemented in the Vensim software based on flow diagrams and differential equations of system dynamics. The accuracy of the model was verified using historical data. With the help of the model, a forecast of demographic determinants up to 2022 was created.**

Keywords—System dynamics; Simulation modeling; Forecasting; Demography; Vensim

I. INTRODUCTION

Demographic processes have a significant impact on the socio-economic life of a country. This is especially true for the various regions of the country. In the study of demographic processes, a systematic approach is needed to assess the problems and methods of solving demographic problems at the regional level.

This study was conducted using the Volga Federal District as an example. There has been a downward trend in the population in the Volga Federal District, which has been persisting over the past few years. From 2000 to 2016, the population of the district decreased by ~1.9 million people. Despite the fact that the birth rate has been growing in recent decades and the mortality rate is slowly decreasing, the natural increase still remains negative. Therefore, the study of factors affecting fertility and mortality is very relevant.

During the research, the following tasks were set:

- Assess and forecast the demographic situation in the region while maintaining current conditions
- Identify possible ways of influencing the situation (select potential regulators);
- Compare different scenarios for the development of the demographic situation in the region due to alternative management decisions (choice between several regulators and their various combinations).

II. MODEL

First, we described the population dynamics (1). The equation takes the following general form:

$$P_{t+1} = P_t + BR_t * P_t - DR_t * P_t + M_t \qquad (1)$$

where P_t is the population in the initial period t, P_{t+1} is the population in the next year, BR_t is the birth rate (number of people born in a year), DR_t is the mortality rate (number of people who die during the year), and M_t is the migration level for the period under review.

To determine the factors affecting fertility and mortality, a sample of 15 medical and socioeconomic factors for the Volga Federal District for 2000-2016 was taken. The resulting (2) and (3) include only significant factors.

The results of the correlation analysis for the selected factors are presented in Fig. 1:

Correlations (stat18)
Marked correlations are significant at p < ,05000
N=17 (Casewise deletion of missing data)

Variable	Emissions	Alcohol	Housing	Household income
Birth_rate	-,8151	-,6975	,9490	,9570
	p=,000	p=,002	p=,000	p=,000
Mortality	,8770	,7488	-,8792	-,9070
	p=,000	p=,001	p=,000	p=,000

Fig. 1. Results of correlation analysis.

Using the above, we obtained the most significant factors that we would use to model the main demographic processes and the formation of corrective actions that could hypothetically change the demographic situation for the better.

These factors were used to construct multiplicative corrections for the main variables: the birth rate and the death rate. The multiplicative correction factors all hover around the value of 1 to include the effects of varying conditions on the system.

It should be noted that multiplicative correction factors have already been used in the works of Forrester and Meadows. In Forrester's concept of "quality of life," the function itself is written down as a product of factors that depend on various socio-economic factors.

The birth rate (with correction factors) is calculated by the formula

$$BR = BRN * AlcCorrB * EmCorrB * HhIncCorrB * HousingCorrB \quad (2)$$

where BR is Birth Rate, BRN is Birth Rate (Normal), AlcCorrB is Alcohol Consumption Correction of Birth Rate, EmCorrB is Emission Correction of Birth Rate, HhIncCorrB is Household Income Correction of Birth Rate, and HousingCorrB is Housing Level Correction of Birth Rate.

The death rate (with correction factors) is calculated by the formula

$$DR = DRN * AlcCorrD * EmCorrD * HhIncCorrD * HousingCorrD, \quad (3)$$

where DR-death rate; DRN-Death Rate (Normal), AlcCorrD-Alcohol Consumption Correction of Death Rate; EmCorrD-Emission Correction of Death Rate, HhIncCorrD-Household Income Correction of Death Rate; HousingCorrD - Housing Level Correction on Death Rate.

Each of the multiplicative corrections (4) describing the dependence of the birth rate / death rate on the corresponding factor can be described as follows:

$$BrCorr = 1 \mp \frac{N1-BrSt}{N1} \quad (4)$$

Where N1 is the the actual value of factor 1, and BrSt is the dependence of the birth rate / death rate on factor 1 calculated using the regression equation.

Birth Rate (Normal) and Death Rate (Normal) are set as a time series.

III. SIMULATION

Simulation modelling can be used to avoid the counterintuitive behaviour of the socio-economic system [1]. With the help of modelling, it was possible to understand the internal mechanisms of the development of various economic processes, hiding behind a visible, often seemingly paradoxical, picture of economic phenomena that did not fit into well-known theoretical schemes [2, 3]. Experience in the use of models has shown that they serve as a reliable tool for analysing macroeconomic patterns, as well as predicting the consequences of macroeconomic decisions, provided that the existing relations are maintained [4].

With the help of system dynamics, it is possible to forecast the dynamics of changes in the basic socioeconomic parameters of the region due to the presence of differential equations, as well as dependencies on lag variables obtained by the tools of econometrics or neuroinformatics [5]. System dynamics can identify cause-effect relationships and global interdependencies in the system under consideration.

To implement the dynamic model of the demographic situation of the district, a method of system dynamics was chosen, which is based on four principles [6, 7]:

- All changes in any system are conditioned by "feedback loops";
- The dynamics of the behavior of an arbitrarily complex process can be reduced to a change in the values of certain "levels," and the changes themselves can be regulated by flows filling or exhausting the levels;
- Feedback loops in any system are often connected non-linearly;
- System dynamics can most accurately reflect the non-trivial behavior of a network of interacting variables and feedbacks [8].

A flowchart of the model of the system dynamics of the demographic situation is shown in Fig. 2. The model was implemented in Vensim [9].

All correction factors are considered in the dynamics, adjusting the resulting indicators of the birth rate, mortality, and population.

The model was calibrated before the analysis was performed. Simulation results were compared with actual historical data to verify the extent of their accuracy, in order to assess the reliability of the model's parameters. The Fig. 3 illustrates the real historical data of Population and data that we got from simulation model.

The simulation length is from 2000 to 2022, or a total of twenty-three years. The simulation time step is one year. The model calibration stage is focused on obtaining reasonable parameter values by matching model output to historical data, while the model prediction stage focuses on projecting the future Population using the calibrated parameter values.

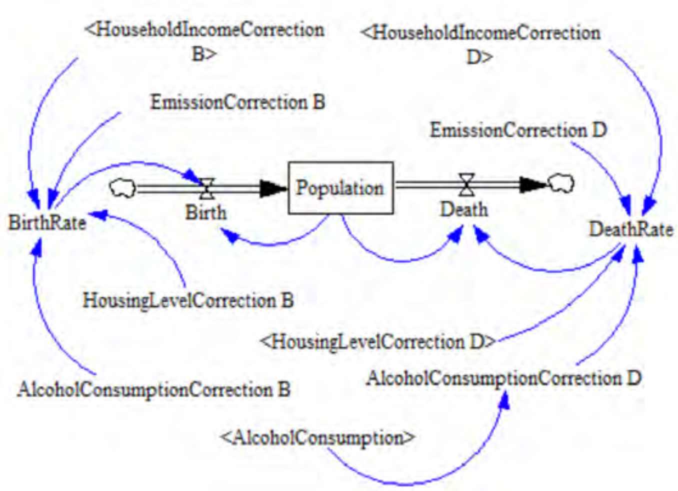

Fig. 2. Flowchart of the model.

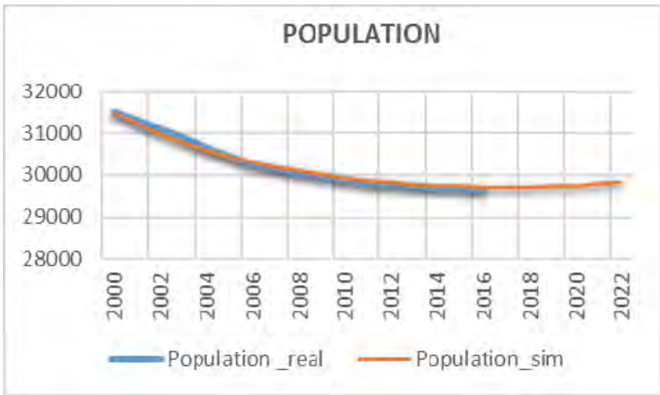

Fig. 3. Population: historical data and Simulation results.

After the model is tested to fit with historical data, it is possible to consider scenarios for improving the demographic situation. The Vensim software allows users to make changes to the parameters and watch the dynamics of changes in the indicators they are interested in [10]. Consideration of various scenarios can help to discover what measures need to be taken to change the situation for the better.

Fig. 4 shows different scenarios, including changes in both mortality and fertility rates and the factors that affect them. The curve labeled *current_1* shows the current situation or Scenario 1 which is also known as the trend-based scenario by assuming that the development policies and system structure do not have a large adjustment in the forecasting period. We see that dynamics of Population is negative. The *current_2* curve illustrates a situation where the fertility rate increases from 8.8 to 9.5 per 1,000 and Death rate decreases from 15.3 to 14 per 1,000. Other parameters of this scenario keep the same as scenario of *current_1* graph. We can see that situation is better but the graph of Population still has a negative trend. In order to stabilize the situation, it is necessary to take a set of measurements that would affect to the fertility and death rates. The *current_3* curve shows the results of changes in such factors as atmospheric emissions and alcohol consumption.

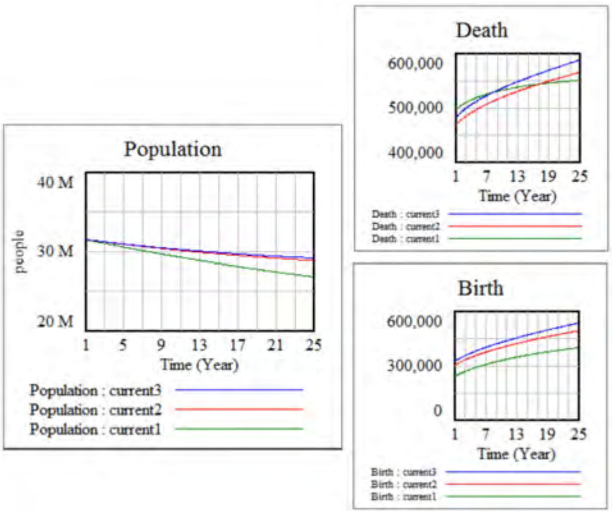

Fig. 4. Results of the model simulations.

We see that the changes made to the model only slightly improve the Population value. This is quite an adequate result, since for a fundamental change more serious systemic measures are needed.

IV. Results

As a result of the study, the following conclusions can be drawn.

1. With the help of correlation analysis, the most significant socioeconomic factors that affect the total fertility and mortality rates are revealed.

2. Regression equations were constructed to determine the degree of influence of the investigated factors on the birth and death rates.

3. The model is a system dynamic simulation model of the demographic state of the Volga Federal District.

4. Using the model, a forecast is made for the next 5 years.

5. It is shown that by influencing the factors under analysis, it is possible to improve the demographic situation. However, changes will occur only after gaining inertia.

Thus, the developed simulation model makes it possible to predict the population size while taking socio-economic factors into account.

In order to stabilize the population through all areas of demographic development it is necessary to implement a long-term state demographic program for reducing mortality, increasing birth rates, regulating migration in accordance with the needs of socio-demographic development. The following measures should be taken:

- reduction of mortality from preventable causes;
- improving the functioning of the health care system;
- strengthening measures of social support for families, introducing, in addition to general federal measures, a set of measures to counter the poverty of families with children and certain categories of families in a social risk zone;
- ensuring the needs of families in pre-school, school and out-of-school education, increasing accessibility and quality of their services;
- assistance in creating a habitat conducive to families with children;
- development of the housing market and increasing the availability of housing that meets the needs of families, accelerated development of social infrastructure that meets the needs of the population for managing a healthy lifestyle;
- promoting the development of flexible forms of employment for women with children;
- attraction of migrants arriving to the territory of the district, permanent residence, assistance in their adaptation and integration into the receiving society;

- assistance in economically justified attraction of temporary labor migrants, simplification of procedures for their hiring.

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