HMMOCS-II 2023: Hybrid methods of modeling and optimization in complex systems

«Application of mathematical methods to solving problems of digitization of population movement»

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In the modern world, digitalization is an important tool for the effective development of territories. Digital technologies make it possible to meet the high rates of development in many sectors of human activity and the high rates of development of science and technology.

The purpose is to develop a consistent scheme of population flows for the purpose of its further digitalization, as well as the use of data mining methods for modeling and forecasting the characteristics of human capital. A sequential research plan involves solving 4 problems:

1) to construct a diagram of a person’s digital trace over time;

2) to structure of demographic flows and a number of socio-economic processes (education, healthcare, culture) using available dynamic data on the digital traces of the population; Big Data technology is used to solve the problem;

3) to study of the characteristics, properties, qualities of demographic flows; Data analysis technology is used to solve the problem;

4) to analyze and forecast of quantitative and qualitative characteristics of population flows; Data Science technology is used to solve the problem.
The methods are mathematical methods for processing statistical data are used, such as methods of correlation and regression analysis, constructing mathematical models, forecasting methods, artificial intelligence algorithms, neural network models.

To model the age dynamics of demographic elements, the following equation is used:

\[ \frac{\partial \rho(t, \tau)}{\partial t} + \frac{\partial \rho(t, \tau)}{\partial \tau} = -\mu(t, \tau) \rho(t, \tau) + l(t, \tau) \rho(t, \tau). \]  

(1)

where \( \rho(t, \tau) \) is the population density by age \( \tau \) per year \( t \); \( \mu(t, \tau) \) - coefficient of distribution of population mortality by age, which specifies the proportion of deaths in an age group \( \tau \) per year \( t \); \( l(t, \tau) \) - migration interaction coefficient, which specifies the share of migrants in an age \( \tau \) per year \( t \).

Initial condition for (1) is

\[ \rho(t_0, \tau) = \rho_0(\tau), \quad \tau > 0. \]  

(2)

Boundary condition for (1) is

\[ \rho(t_0, \tau) = \int \beta(t, \tau_0) \rho(t, \tau_0) d\tau_0, \quad t > t_0, \]  

\( \tau\leq\tau_0 \)  

(3)

where \( \beta(t, \tau) \) is the coefficient of distribution of births by age, which specifies the proportion of births in each age \( \tau \) per year \( t \) (density of distribution of births from the range of women’s fertility \( [\tau_l; \tau_u] \)).

\[ \text{Figure 1: Algorithm for digitalization of population movement} \]

\[ \text{Figure 2: Density of population distribution} \]

\[ \text{in the Udmurt Republic by ages in 2000 and 2020} \]

\[ \text{Figure 3: Gradients of characteristics} \]

\[ \text{of demographic elements of society} \]
Conclusions

Results, implementation

We see that the use of a database of digital information on the movement of demographic flows and the use of Data analysis technology to study their characteristics will generate a large amount of information that needs systematization to organize it and identify internal relationships. This problem is solved using Data Science technology, and has already been partially solved using the proposed mathematical models.

• The use of mathematical models and Data Analysis technology allows you to obtain important results necessary for assessing the current state of the system, its analysis and further planning.

During the period under review, the population of the region decreased by 5.9% compared to 2000. The average annual rate of population decline in the UR was 0.3%. Population dynamics are influenced by fertility and mortality. The maximum birth rate for the period was recorded in 2012 (23.2 thousand children), the minimum in 2020 (14.5 thousand children). For the mortality rate, the highest value was recorded in 2003 (24.6 thousand people), the lowest value was in 2019 (17.9 thousand people), while for the period 2003-2019 there is a visible trend towards a decrease in mortality (average annual rate a decrease of 2.0%), but 21.1 thousand people died in 2020, which is 17.9% more than the previous year.

Figure 4: Dynamics of the population structure of the Udmurt Republic by age groups
Figure 5: Dynamics of the population structure of the Udmurt Republic by level of education
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