Розроблено науково-методологічні та функціональні принципи інтелектуальної системи підтримки прийняття рішень з управління демографічною ситуацією на основі прогнозів. Прогнози змін чисельності населення, його віково-статевої структури, народжуваності, тривалості життя, смертності і т. д. складають основу соціально-економічного розвитку. Таким чином, розглянуто моделювання демографічних процесів для прийняття науково обгрунтованих рішень, що стосуються управління майбутньою демографічною ситуацією. Проаналізовано характеристики процесу та виявлено ознаки, що обгрунтовують виникнення цього процесу в умовах невизначеності і нечіткості. Для моделювання демографічних процесів запропонована нечітка модель часових рядів. Розроблено метод демографічного прогнозування на прикладі прогнозування загальної чисельності населення. На основі запропонованого методу розроблено програмне забезпечення для системи демографічного прогнозування. Представлена функціональна схема системи, розкрито принцип роботи її блоків і їх взаємодії. Описано принцип роботи бази знань, яка виконує аналітику прогнозів і ідентифікує прогнози, пов'язані з демографічною ситуацією, посилаючись на модель виробництва знань. Реалізація такої системи може допомогти демографам та аналітикам у прогнозуванні майбутньої демографічної ситуації та прийнятті рішень з управління відповідною демографічною ситуацією

Ключові слова: демографічні процеси, зростання населення, метод демографічного прогнозування, нечіткі часові ряди

UDC 314

DOI: 10.15587/1729-4061.2019.178440

DEVELOPMENT OF INTELLIGENT DEMOGRAPHIC FORECASTING SYSTEM

Z. Jabrayilova
PhD, Associate Professor
Department 15
Institute of Information Technology of the National Academy of Sciences of Azerbaijan
B. Vahabzada str., 9A, Baku, Azerbaijan, AZ1141
E-mail: djabrailova_z@mail.ru

Received date 01.07.2019
Accepted date 10.09.2019
Published date 31.10.2019

1. Introduction

There is no area of economic and social life that would not take into account the changes taking place in demographic processes. Socio-economic processes in the society are interconnected with demographic processes; the demographic policy is an important element of the social policy of each state. The main purpose of this policy is to achieve favorable conditions for the constant generation of population. This is in line with the interests of society and its members, taking into account the most important factors affecting demographic phenomena. Affecting the domestic and foreign policies of the states, the demographic changes in the modern world require to focus on the statement and solution of many problems from the demographic aspect [1, 2]. Thus, to implement effective demographic policy in the country, to effectively manage human resources, it is important to:

– study the existing demographic situation and its interaction with socio-economic processes;

– define the prospects of demographic development;

– forecast the population development and conduct an analytical analysis of the results.

Solution of these problems requires the consideration of the monitoring and forecasting of demographic aspects of human resources, as a strategic resource of the country [1]. Demographic forecasts allow for defining the number of people in the perspective, which is an integral element of socio-economic development (general population, able-bodied population, economically active population, population of different age groups, births, deaths, etc.) [3]. The results of this forecast and their analytical analysis constitute the basis for the development and realization of a scientifically justified socio-economic development policy and the formation of multifaceted practical practices.

These findings are often used to make decisions and take appropriate measures in the following cases [4]:

– determining the demand for food, energy, housing, social household, health, education, transport and other services (population forecast by general and individual age groups);

– developing pensions, social and health insurance programs (population forecast by age, gender and family structure, including the proportion of able-bodied and disabled people);

– developing national and regional development programs, drafts on individual areas (forecasting the total number of population, predictions of individual socio-demographic groups and reproduction of population);

– developing population growth policy and/or human development program;

– determining the economic growth rate (number of (employed) population, its education, age and family structure);

– determining the volume of the market of certain products and services (prediction of individual socio-demographic groups, forecast of birth, death, marriage rate);

– projecting the development models for scientific researches (forecast of population, individual socio-demographic groups and population reproduction rate);

– evaluating the conditions of the environment (population's size, prediction of individual socio-demographic groups);

– formation of constituencies and election companies (forecast of population's number, individual socio-demographic groups.

Each of these issues constitutes the basis of the socio-economic development of the state and the human resource management policy in macroeconomics. Therefore, the correct and flexible solution of these issues requires the prediction of the changes related to the number of population, its age-gender structure, birth, mortality, life expectancy, etc. Such predictions constitute the basis for the management of demographic situation, and thus, improvement of this process through the advanced intelligent technologies is relevant.

Thus, the submitted paper presents the scientific and functional principles for the development of a demographic forecast system that supports decision making on the above-mentioned issues. These principles are based on: fuzzy time series model for population forecasting; knowledge production model; intelligent systems design technologies.

2. Literature review and problem statement

Demographic forecasting can be described in the following steps [5, 6]:

– selecting an object to be predicted;
– selecting the prediction period;
– selecting the prediction base;
– selecting the scenario to be predicted;
– selecting the forecasting method and model;
– and model calculations and results analysis.

Thus, many scientific works focus on these stages of demographic prediction. The methods used in demographic prediction are analyzed. Accordingly, the methods used in demographic prediction can be classified as follows:

1) extrapolation method: [7–11] describe the opportunities of using this method to estimate a future number of population. This method is based on the idea that the predicted tendencies of birth, mortality and migration will not change in the predicted period;

2) method of age replacement: the method used in [12, 13] is a promising method for calculating the age structure of the population. This method is based on the use of the data related to the life expectation (coefficient) of the population and the rate of mortality provided in the table. This method supposes the preservation of the existing order of extinction of the population in the future;

3) statistical modeling methods: comprise the use of a regression model characterizing the dependence of demographic situations on certain factors [14, 15]. One of these methods is the ARIMA-modeling (Autoregressive Integrated Moving Average Model), which bases on the "pure time-series" approach. This approach was first proposed in 1970 [16] and improved editions are used for different demographic situations [15, 17];

4) stochastic modeling methods: the advantage of this technique is determined by the availability of a parameter varying for the time in a simple stochastic model, and often provides better performance when the previous tendencies are linear [8, 18–20]. [18] uses the standard time series for demographic predictions.

[21] highlights the application opportunities of adaptive and imitation models, smooth dynamic series, autoregression, etc. for the prediction of the population number.

In general, the application of conventional analysis methods in demographic forecasting is based on the population growth modeling referring to the processing of numerical data. For example, prediction of the future number of population uses the numerical methods of classical mathematical apparatus based on the average growth rate, general growth coefficient, etc. as the statistical characteristics [7, 14]. Nonetheless, the high accuracy performed by the numerical methods of classical mathematical apparatus does not coincide with the great complexity of the population growth process. Thus, the methods aimed at the mathematical analysis of precision systems are not capable to take into account a number of existing features of the object of the study. The distinctive feature of this object is its functionality in uncertainty [22]. Taking into account this reality, it is necessary to use the fuzzy apparatus to predict the population growth. Many studies on prediction issues have started to use fuzzy logic [23, 24]. These studies present a description of the mathematical model of fuzzy time series for solving the problem based on the fuzzy input information. Subsequently, this field was developed by other specialists dealing with analogical problems [25–27]. In these studies, the authors attempt to improve the accuracy of predictions by making certain changes in the fuzzy time series model. [28, 29] present the analysis of results achieved for the population growth by referring to the prediction technique based on fuzzy time series. They also provide that the error is less than those of other methods.

The articles focused on the approaches aimed at ensuring the prediction accuracy being restricted to:

– error calculation after being tested [8, 10, 11, 13–15, 24–29];
– development of software product that presents predictions [12, 16, 17];
– interpretation of the results obtained at the expert level [9, 16, 18–20].

These studies do not explore the system development which performs the analysis of the forecast results using intelligent technologies and makes necessary decisions for the future demographic situation management. The principles of developing the decision support system for future demographic situation management in accordance with the results of the fuzzy prediction technique are presented.

3. The aim and objectives of the study

The aim of the study is to develop an Intelligent Demographic Forecasting System that supports demographic situation management decisions based on predictions (forecasts). To achieve this aim, the following objectives are accomplished:

– to model the demographic process;
– to develop the demographic prediction technique;
– to determine the effectiveness of the proposed technique;
– to develop a decision support system for the management of demographic situation based on the proposed technique.

4. Modeling demographic processes

The development of information technologies and software resources has opened up new opportunities for modeling demographic processes and handling forecasting problems. Recent studies prove that the application of traditional analyzing methods and modeling of population growth based on numeric/quantitative data processing don't produce the desired results. They even involve considerable risks and errors. One of the main causes for this undesirable circumstance stems from the fact that many forecasting models are not sufficiently efficacious. This is due to the incompatibility of highly accurate quantitative methods of classical mathematical apparatus with the great complexity of population growth [30, 31].

The other cause, in our opinion, is that these methods aimed at the mathematical analysis of accurately determined systems are not capable to encompass certain characteristics of the research sphere.

Thus, population is a large dynamic (economic, social, ecological) system, irrespective of a specific territory and definite group. A distinguishing feature of this system consists of its functioning under indefinite, uncertain conditions due to a multitude of causes. These uncertainties are, first of all, associated with:

– the impossibility of identifying all the factors that determine the development dynamics of human population;

– variability and inconstancy of boundaries of many indicators used in demographic analysis and considerable variations in the values of some indicators;

– the lack of comprehensive prior information pertaining to demographic processes associated with the data source problems and impossibility of recording all the demographic events.

This list of causes may include data incompleteness, uncertainties involved while collecting some indicators from various sources. These sources are the results of population census and demographic researches, current registration of population movement, etc. Discrepancies between official and unofficial data, expert evaluations can cause further difficulties.

Population growth is a multi-factored and time-dependent process. But it is not possible to consciously influence this process by varying certain parameters and observing changes in others.

Various uncontrollable factors (wars, inter-ethnic conflicts, natural disasters, ecological factors, etc.) significantly affect population growth. If systematic statistical material with regard to the concerned problem is lacking, empirical data become the sole information source.

Thus, keeping in mind that the demographic data are incomplete and accuracy of some or all the available data is questionable for any of several reasons, a demographic analysis based on this incomplete, inaccurate information bears a special significance. The vagueness, inaccuracy, incompleteness, fuzziness of the data necessitate taking a new approach to the analysis and evaluation of demographic situations, particularly, population growth forecasting.

Within the context of the above-mentioned arguments, exploring the possibilities of the application of the fuzzy sets theory or the apparatus of sets, going by the name of fuzzy logic, to modeling demographic processes bears a special interest.

5. Applications of the fuzzy sets theory in demographic forecasting

The advent of fuzzy logic made it possible to tackle a great many problems with fuzzy input data [22]. One of them was a forecasting problem. Many of the structural elements of the latter are either of a fuzzy nature or, being in fuzzy relationships, require the fuzzy description of the problem. These elements include the input data and interdependence between its components, interval evaluation of indicators and their interdependence, expert evaluations and judgments, etc.

The above-mentioned features of population, functioning under indefinite, uncertain circumstances, condition the fuzziness of input data or "load" the task onto fuzzy environment. Therefore, from both theoretical and practical standpoints, handling the concerned problem based on fuzzy time series would be more expedient.

Thus, the major purpose of the proposed approach is methodological:

– putting forth an evaluation method based on fuzzy time series for estimating model parameters;

– testing the extent to which the model is adequate to reflect the real process, that is to say, computing the method error;

– conducting the comparative analysis of computation results;

– revealing the practical and theoretical importance of the model.

6. Brief information on fuzzy time series

Time series represents a consecutive series of observation that is conducted by equal time intervals and lies at the root of exploring real processes in economics, meteorology and natural sciences, etc.

The analysis of time series of observation consists of the followings:

– constructing the mathematical model of time series of observation of real processes;

– model identification or selection of quantitative evaluation/estimation method for assessing model parameters in order to test the extent to which the model is adequate to reflect the real process;

– conversion of the identification model into time series through the statistical evaluation of model parameters.

Formally, time series can be defined as a discrete function $x(t)$ whose argument and function values are dependent on discrete time moments as well as argument values, function values at different time intervals.

It is assumed, the time interval $0\le t\le T$ of process $x(t)$ is observed, that is to say, the parameter t varies along the time interval $[0, T]$ (set R) or assumes any integer belonging to this interval. For every fixed time moment $t=s$, the function value is determined by the function arguments values at all time moments from $t=0$ to $t=s-1$, and the function value at all time moments from $t=0$ to $t=s-2$.

Fuzzy time series. Let us assume that $U=\{u_1, u_2, \ldots, u_n\}$ is a universal time set. The fuzzy set A of universal set U is defined as follows:

$$A=\{(\mu_A(u_1)/u_1),\ (\mu_A(u_2)/u_2), \ldots ,(\mu_A(u_n)/u_n)\}$$

or

$$A=\{(\mu_A(u_i)/u_i)\},\ i=\overline{1,n},\ u_i\in U,\ \mu_A(u_i)\in[0, 1],$$

where $\mu_A(u_i)$ is the membership function; $\boldsymbol{\mu}_A(u_i){:}U\Rightarrow[0, 1]$, is the degree of belonging of u_i to the set A; "/" is the division sign.

Let us assume that $Y(t)$ (t=...., 0, 1, 2...), which is a subset of set R of real numbers, is simultaneously a universal set on which a fuzzy set $\mu_i(t)$, (t=1, 2, ...) is defined, that is to say, the membership function is time-dependent.

Let us define a set $F(t)$ arranged out of $\{\mu_i(t), t=1,2,...\}$.

More precisely, $F(t)$ is a set of fuzzy sets $F(t)=\{\mu_i(t), t=1, 2,...\}$.

Then $F(t)$ is a fuzzy time series defined on a universal set $Y(t)$ (t=1, 2, 3....). It is evident, if $F(t)$ is accepted as a linguistic variable, the fuzzy sets $\{\mu_i(t), t=1, 2,...\}$.

Out of which we arranged $F(t)$ will assume the possible corresponding values of $F(t)$. Besides, as is evident, $F(t)$ is time-dependent, which means, the function $F(t)$ will assume different values at different time moments.

7. Fuzzy time series model of the demographic forecasting

Problem statement. The intensive changes in demographic processes that are caused by the influence of the social-demographic factors, have rendered the determination of perspective variation in the total population, one of the most important tasks to be tackled for demographic forecasting. To solve the task of forecasting the total population, we have introduced a model of fuzzy time series in this article. More precisely, the problem is described as follows: for a given time interval, data pertaining to the total population in Azerbaijan or to be more clear, the dynamics and respective variation of the total population are available. The point is to find the anticipated total population based on the variations of the previous years.

Problem solution. In accordance with the description of the problem, the following forecasting methodology is proposed:

1. Finding appropriate variations of population dynamics in the country for a certain period (e. g. 1980–2001).

2. Definition of universal set U containing the interval between the least and greatest variations in the total population.

3. Division of the universal set U into equal-length intervals containing variation values corresponding to different population growth rates and the arithmetic mean of each interval is found by the following formula:

$$u_m^j = \frac{\max(u_j)+\min(u_j)}{2},$$

where $\max(u_j)$ is the largest values of interval j, respectively; $\min(u_j)$ is the lowest values of interval j, respectively.

4. The qualitative description of variation values of the total population as a linguistic variable, that's to say, determining the respective values of the linguistic variable or the set of fuzzy sets $F(t)$.

5. Fuzzification of the input data or the conversion of numerical values into fuzzy values, by the following formula:

$$\phi_{A_j}(u_j) = \frac{1}{1+\left[C\cdot\left(U-u_m^j\right)\right]^2},$$

where U – variations; $u^j{}_m$ is the middle point of the corresponding interval; C is a constant. C is chosen in such a way that it ensures the conversion of definite quantitative values into fuzzy values or their belonging to the interval [0, 1]:

$$A_j = \phi_{A_j}(u_j)/u_j,\ u_j \in U.$$

Here $\phi_{A_j}(u_j)\in[0, 1]$ is the fuzzy set (in our case C=0.0001). This operation enables us to reflect the corresponding numerical/qualitative values of qualitative representations of population growth rates in the value of membership function.

6. Selection of parameter W>1, corresponding to the time period prior to the concerned year, calculation of fuzzy relationships matrix $R(t)$ and forecasting of population growth in the next year. According to the method, the relationship matrix $R(t)$ is calculated at the next step:

$$R(t)[i,j] = O^w(t)[i,j]\cap K(t)[j]$$

or

$$R(t)=O^w(t)\otimes K(t)=\begin{vmatrix} R_{11} & R_{12} & \dots & R_{1j} \\ R_{21} & R_{22} & \dots & R_{2j} \\ \dots & \dots & \dots & \dots \\ R_{i1} & R_{i2} & \dots & R_{ij} \end{vmatrix}.$$

Here $O^w(t)$ is the operation matrix; $K(t)$ is the criterion matrix; $\otimes$ is the operation min ($\cap$).

Later, the forecasted value $F(t)$ for the t year is defined in a fuzzy form as follows:

$$F(t)=\begin{bmatrix} \max(R_{11},R_{21},...,R_{i1}) & \max(R_{12},R_{22},...,R_{i2}) & \dots \\ \dots & \max(R_{1j},R_{2j},...,R_{ij}) & \end{bmatrix}.$$

7. Defuzzification of the obtained results or conversion of fuzzy values into qualitative values. The application of the proposed technique in forecasting demographic indicators (total population, able-bodied population, economically active population, births, deaths, different age groups) of the population in Azerbaijan is described in [28, 29].

8. Determining the efficiency of the proposed technique

Based on the proposed technique, the estimates of population numbers for 2002–2016 are calculated based on the total number of population in Azerbaijan for 1981–2001. They are compared with the results obtained from other forecasting models (SPSS software referencing to the World Bank's PROST model and statistical forecasting model). The results are given in Table 1.

The relative error of the submitted method is calculated by the following formula:

$$\delta(t)=\frac{\left|N(t)_{act.}-N(t)_{forec.}\right|}{N(t)_{forec.}}\cdot 100\ \%.$$

Here $N(t)_{act.}$ is the number of actual population for year t; $N(t)_{forec.}$ – forecasted number of population for year t, $2002\le t\le 2016$.

The relative errors of the forecast results show that the proposed method can be used as an alternative approach to predicting demographic parameters (7–8 % of estimation errors are acceptable). Thus, executed experiments and comparisons show that the use of this approach is promising for short-term forecasting.

Table 1

Dynamics of population (thousand people) in Azerbaijan for 2002–2017 with the use of different forecasting models and relative errors (source for actual population number [32])

Years	PROST	SPSS model	FSM	Actual	Error, %		
					PROST	SPSS	FTS
2002	8200.189	8141.41	8155.3	8191.4	0.11	0.61	0.44
2003	8277.965	8205.278	8233.8	8269.2	0.11	0.77	0.43
2004	8357.393	8277.211	8315.2	8349.1	0.10	0.86	0.41
2005	8438.496	8356.911	8398	8447.4	1.20	1.08	0.70
2006	8521.262	8450.611	8481.9	8553.1	1.37	1.2	0.83
2007	8606.523	8540.611	8566.7	8666.1	1.69	1.45	1.15
2008	8694.348	8646.278	8652.3	8779.9	0.96	1.52	1.45
2009	8784.848	8758.811	8738.5	8897.0	1.26	1.55	1.78
2010	8878.074	8876.011	8825.3	8997.6	1.33	1.35	1.91
2011	8974.047	8989.394	8912.5	9111.1	1.50	1.36	2.18
2012	9070.694	9099.561	9000	9235.1	1.78	1.47	2.54
2013	9168.131	9209.906	9087.8	9356.5	2.01	1.57	2.81
2014	9266.445	9322.628	9175.9	9477.1	2.22	1.63	3.18
2015	9365.678	9437.628	9264.2	9593.0	2.37	1.62	3.43
2016		9544.478	9352.6	9705.6		1.66	3.64

9. Functional princes of the intelligent demographic forecasting system

Relevant algorithm and software tool were developed on the basis of the proposed technique, and an intelligent demographic forecasting system (IDFS) was built. The system was implemented in the Delphi 7 programming system. The system provides predictive estimates for various demographic indicators for any year or for the coming years. For example, Fig. 1, 2 depict software windows that show the total population for 2018, the estimated values for the years of 2018–2034, respectively.

The IDFS functional scheme includes the following blocks (Fig. 3).

Interface Block enables communication between the system and the user. The user selects the system operating mode via the interface block. The system can operate in three modes: knowledge base building mode, forecasting mode of forecasting results on certain demographic indicators and decision making mode that shapes the demographic policy of the country based on the forecasting results analysis.

Data base is composed of the initial data required for forecasting results based on the offered technique. More precisely, these data include the following:

– statistical values for the studied period for a certain demographic indicator;

– variations;

– maximum and minimum values of the variations;

– universal multiplicity U;

– numbers D_1, D_2 selected to smooth the boundaries of universal multiplicity U.

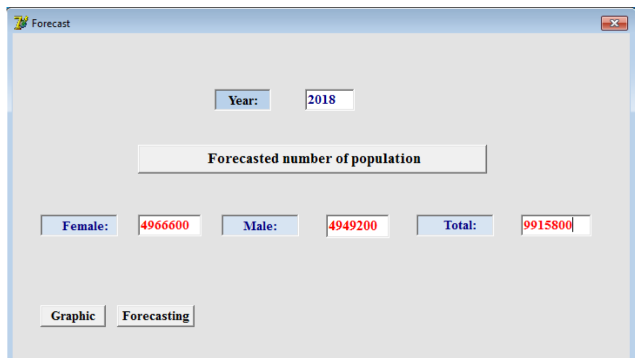
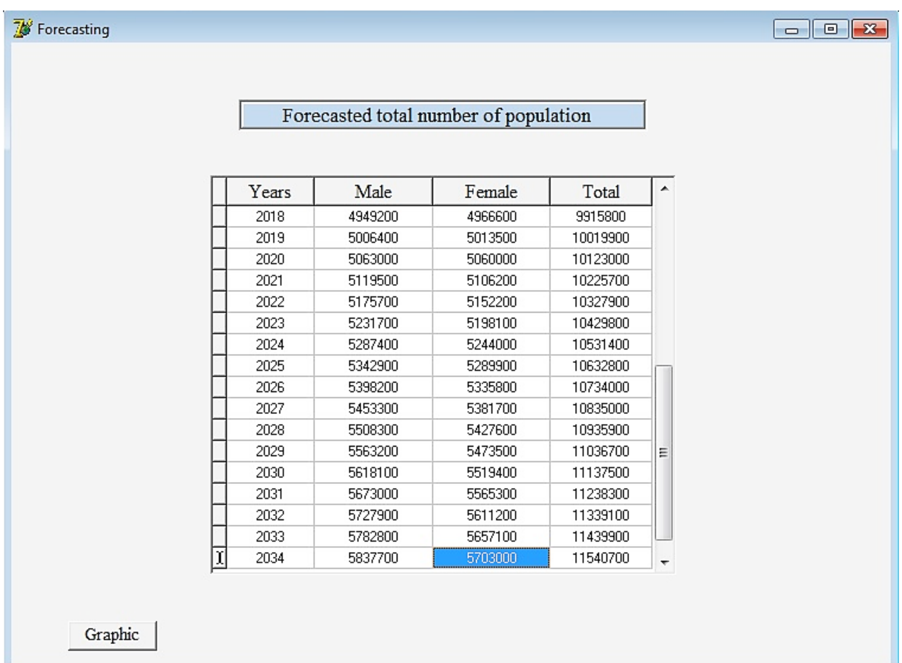


Fig. 1. Software windows IDFS that show the total population for 2018

This block also includes the forecasting results and the result of enabled Rule in accordance with the forecasting results analysis, i. e., the decisions made.



Years	Male	Female	Total
2018	4949200	4966600	9915800
2019	5006400	5013500	10019900
2020	5063000	5060000	10123000
2021	5119500	5106200	10225700
2022	5175700	5152200	10327900
2023	5231700	5198100	10429800
2024	5287400	5244000	10531400
2025	5342900	5289900	10632800
2026	5398200	5335800	10734000
2027	5453300	5381700	10835000
2028	5508300	5427600	10935900
2029	5563200	5473500	11036700
2030	5618100	5519400	11137500
2031	5673000	5565300	11238300
2032	5727900	5611200	11339100
2033	5782800	5657100	11439900
2034	5837700	5703000	11540700

Fig. 2. Software windows IDFS that show the estimated values for the years of 2018–2034, respectively

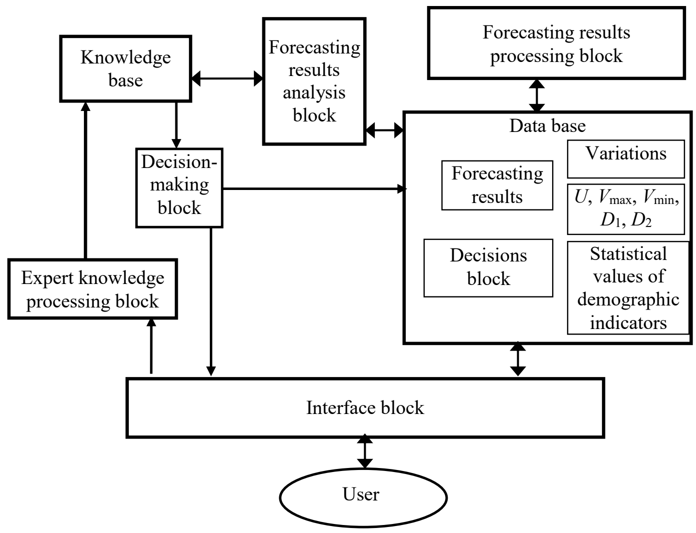


Fig. 3. IDFS functional scheme

Forecasting results processing block gets the results based on the proposed forecasting method for demographic indicators. This block calculates the fuzzy multiplication matrix of the forecasted year by fuzzification of variations and calculation of the operation matrix and criterion unique matrix of the chosen basis. Here, the operation of obtaining forecasting results for the corresponding demographic indicator for the predicted year based on its defuzzification is realized.

Forecasting results analysis block reveals the facts about the demographic situation based on the analysis of forecasted values of certain indicators.

Knowledge base consists of the rules formed as a result of expert knowledge processing. The part "if" in the production rules "If, then" corresponds to a certain fact revealed from the analytics of the forecast results, and the part "then" can be any decision or measure to be taken in accordance with the appropriate demographic policy.

If the condition of the Rule coincides with any fact received from the analytics block, then the Rule is enabled, the second part "then" enters the *decision making block* and is presented to the user as a valid decision and stored in the DB.

Based on the enabled Rule included in the IDFS knowledge base, the mechanism for obtaining the results (decision, the action to be implemented) is introduced as the following rule. This Rule is based on the gender analysis of "predictive results of the right ones".

Rule 1. If *a continuous gender ratio breach is observed in the predicted number of births (often decrease in females and increase in males),* ***then*** *the gender structure of the population changes, and the measures should be taken to prevent the gender ratio breach.*

The procedure for obtaining a result (decision) according to Rule 1 is as follows:

– initial forecast year for the births by gender in the estimations is t;

– $Q(t)$ – the number of females born in the first forecast year;

– $O(t)$ – the number of males born in the first forecast year.

In this case, the rules are formalized through the following condition operator:

*"**If** (Q(t)/O(t)>Q(t+1)/O(t+1)>Q(t+2)/O(t)...), **then** "the measures should be taken to prevent it".*

This Rule is based on the analytics of the forecasts of the number of births by gender for the predicted years (Fig. 1, 2). For example, if t=2018, then the Rule can be described as follows:

*"**If** Q(2018)/O(2018)>Q(2019)/O(2019)>Q(2020)/O(2020)>Q(2021)/O(2021)>...), **then** the measures should be taken to prevent the gender ratio breach".*

If the condition of the Rule is met according to the obtained forecast results, the Rule is enabled and the system presents the *decision* to "take measures to prevent the gender ratio breach".

Referring to the results of the forecast of the gender ratio at birth given in Fig. 2, there is no doubt that this Rule will be applied. Based on the outcome of the forecast, this approach allows for more effective decisions on human resources management at the state level, supports the measures on elimination of the undesirable demographic situation.

Indeed, in recent years there has been a tendency towards gender ratio breach (reduced rate of girls born to boys) in Azerbaijan. One of the facts that accelerated this tendency is the identification of a child's gender in the mother's womb and artificial interruption of pregnancy if a child's gender is a girl. Thus, measures were taken to prevent this tendency at the state level, amendments were made in the law of the Azerbaijan Republic On Protection of Health of Population and it was stated in Article 11 of the law "Artificial interruption of pregnancy and ... prohibited" [33].

10. Discussion of the results of the study on the development of the intelligent demographic forecasting system

The article proposed scientific and methodological principles for the development of an intelligent demographic forecasting system. These principles included: forecasting technique of demographic indicators based on fuzzy time series; software products that process forecasting results; the forecast is based on the development of the system supporting expected demographic situation management decisions based on the results.

In this study, the solution of the demographic prediction problem is further developed referring to intelligent technology. Thus, in the studies [8, 10, 11, 13–15, 24–29], the methods for demographic prediction are proposed and tested, and errors were calculated. The studies [12, 16, 17] describe software products that provide forecasting results. An expert interpretation of the forecast results is given in [9, 16, 18–20]. In the present work, the development of the system that determines the expected demographic situation and makes decisions related to its management, and develops its architectural and functional principles referring to the knowledge production model for the interpretation of the results is considered.

The aspect of application of the scientific results obtained in this study is determined by the development of software products that provide forecast results on demographic indicators. The decision-making mechanism in the intelligent demographic forecasting system is illustrated by a single rule knowledge base. The knowledge base of the system needs to be fully formed in order to support the decision makers in managing demographic situations.

The next phase of this study involves the acquisition of knowledge from expert demographers who interpret the forecast results of demographic indicators; modeling based on knowledge production models; establishment of the knowledge base of the system; and determination of the adequacy of the obtained results (decisions).

11. Conclusions

1. A fuzzy time series model of demographic processes was proposed. The specifics of this model is that it does not refer to certain values of the indicators that characterize it for the description of the dynamics of the processes functionalized in an uncertain environment, but it refers to the changing tendencies, which are expressed by the linguistic values at a certain moment of time. Therefore, this model provides such opportunities: the consideration of the intensity of the demographic processes, their multi-factor character, uncertainties of these factors, inaccuracies, incompleteness, inexactness, and the description of its dynamics in specific time intervals.

2. A technique for predicting demographic indicators was proposed. Distinctive characteristics of this technique are the division of the universal set, which is determined based on the variations for a given time period of the indicators, into fuzzy sets (linguistic sets), the fuzzification of the variations, the calculation of the fuzzy value of the growth for the forecast year, and its defuzzification. Therefore, this technique provides such opportunities: calculation of the forecast values of any demographic indicator (overall population growth, able-bodied population, economically active population, population of different age groups, birth, and mortality) for any year or years, either in retrospective or in perspective, with the reference to the variations in a certain period.

3. A software product that produces forecast results of demographic indicators was developed. Distinctive characteristics of this software product are that as input information, it is required to include the value of the basis (W) along with the statistic data for a given period; forecast results for different indicators can be obtained. Therefore, the developed software product provides such features: results for any demographic indicator can be obtained for any year, either in retrospective or in perspective, forecasted results for a certain period can be presented in tabular or graphical form, and the forecast results obtained for various demographic indicators can be stored in the database.

4. Architectural and functional principles of the decision-making system related to the management of the expected demographic situation based on the forecasted results were developed. Distinctive characteristics of these architectural and functional principles are the availability of a knowledge base block, which specifies the expected demographic situation based on the analysis of the forecast results and is created based on the modeling of the knowledge of expert demographers, and the availability of a decision-making block on the management of the expected situation. Therefore, they provide such opportunities: determines the future demographic citations expected by analyzing the forecast results obtained for various demographic indicators and allows for making decisions on the management of these situations.

References

1. Human development (2014). United Nations Development Program. Baku, 373.
2. Demographic forecasts on the gender ratio of children born in Azerbaijan. Available at: https://en.trend.az/azerbaijan/society/2469629.html
3. Kostakov, V. (2013). Demograficheskij faktor v social'no-ekonomicheskom razvitii [Demographic factor in socio-economic development]. Ekonomist, 11, 20–24.
4. Encyclopedic dictionary on population inhabitance (2009). Baku, 415.
5. Ganiev, A. E. (2016). Metody demograficheskogo prognozirovaniya. NovaInfo.Ru, 46-3. Available at: http://novainfo.ru/article/6270/pdf
6. Eliseeva, I. I., Klupt, M. A. (Eds.) (2016). Demografiya i statistika naseleniya. Moscow, 405.
7. Kulikov, V. E. (2013). Osobennosti prognozirovaniya chislennosti naseleniya. Ekonomika i upravlenie: teoreticheskie i prakticheskie aspekty: materialy mezhdunarodnoy zaochnoy nauchno-prakticheskoy konferencii. Novosibirsk: Izd. «SibAK», 97–100.
8. Booth, H., Tickle, L. (2008). Mortality Modelling and Forecasting: a Review of Methods. Annals of Actuarial Science, 3 (1-2), 3–43. doi: https://doi.org/10.1017/s1748499500000440
9. Stoeldraijer, L., van Duin, C., van Wissen, L. J. G., Janssen, F. (2013). Impact of different mortality forecasting methods and explicit assumptions on projected future life expectancy: The case of the Netherlands. Demographic Research, 29, 323–354. doi: https://doi.org/10.4054/demres.2013.29.13
10. Janssen, F., van Wissen, L. J. G., Kunst, A. E. (2013). Including the Smoking Epidemic in Internationally Coherent Mortality Projections. Demography, 50 (4), 1341–1362. doi: https://doi.org/10.1007/s13524-012-0185-x
11. Janssen, F. (2018). Advances in mortality forecasting: introduction. Genus, 74 (1). doi: https://doi.org/10.1186/s41118-018-0045-7
12. Yuzaeva, J. R. (2014). The forecast of the population of the Orenburg region in the context of urban and rural areas by the method of "Advancing ages". Statistics and Economics, 5, 155–160.
13. Vereshchaka, E. G. (2010). Forecasting of basic characterictics of demographic situation. Ekonomika, Statistika i Informatika, 1. Available at: https://cyberleninka.ru/article/n/prognozirovanie-osnovnyh-harakteristik-demograficheskoy-situatsii
14. Kopnova, E. D., Rodionova, L. A. (2016). The Statistical Approach to the Analysis and Forecasting of Demographic Data. Izvestiya of saratov university. New series. Series: economics. Management. Law, 16 (3), 306–315. doi: https://doi.org/10.18500/1994-2540-2016-16-3-306-315

15. Torri, T., Vaupel, J. W. (2012). Forecasting life expectancy in an international context. International Journal of Forecasting, 28 (2), 519–531. doi: https://doi.org/10.1016/j.ijforecast.2011.01.009
16. Box, G. P., Jenkins, G. M. (1970). Time Series Analysis: Forecasting and Control. San Francisco: Holden-Day, 554.
17. Hyndman, R. J., Booth, H., Yasmeen, F. (2012). Coherent Mortality Forecasting: The Product-Ratio Method With Functional Time Series Models. Demography, 50 (1), 261–283. doi: https://doi.org/10.1007/s13524-012-0145-5
18. Lee, R. D., Carter, L. R. (1992). Modeling and Forecasting U.S. Mortality. Journal of the American Statistical Association, 87 (419), 659–671. doi: https://doi.org/10.1080/01621459.1992.10475265
19. Li, Q., Reuser, M., Kraus, C., Alho, J. (2009). Ageing of a giant: a stochastic population forecast for China, 2006–2060. Journal of Population Research, 26 (1), 21–50. doi: https://doi.org/10.1007/s12546-008-9004-z
20. Matysiak, A., Nowok, B. (2007). Stochastic forecast of the population of Poland, 2005-2050. Demographic Research, 17, 301–338. doi: https://doi.org/10.4054/demres.2007.17.11
21. Gerashchenko, I. P. (2000). Metody prognozirovaniya v regressionnyh i adaptivnyh modelyah pri analize dinamicheskih ryadov. Matematicheskie struktury i modelirovanie, 5, 140–154.
22. Zadeh, L. A. (1975). The concept of a linguistic variable and its application to approximate reasoning – II. Information Sciences, 8 (4), 301–357. doi: https://doi.org/10.1016/0020-0255(75)90046-8
23. Song, Q., Chissom, B. S. (1993). Fuzzy time series and its models. Fuzzy Sets and Systems, 54 (3), 269–277. doi: https://doi.org/10.1016/0165-0114(93)90372-o
24. Song, Q., Chissom, B. S. (1994). Forecasting enrollments with fuzzy time series – part II. Fuzzy Sets and Systems, 62 (1), 1–8. doi: https://doi.org/10.1016/0165-0114(94)90067-1
25. Chen, S.-M. (1996). Forecasting enrollments based on fuzzy time series. Fuzzy Sets and Systems, 81 (3), 311–319. doi: https://doi.org/10.1016/0165-0114(95)00220-0
26. Hwang, J. R., Chen, S. M., Lee, C. H. (1996). A new method for handling forecasting problems based on fuzzy time series. Proc. 7th Internat. Conf. On Information Management. Taiwan.
27. Ahmadov, M. Z. (2015). Forecasting based on fuzzy time series. Baku, 136.
28. Mamedova, M. G., Dzhabrailova, Z. G. (2005). Fuzzy Logic in Forecasting of Labor Market Demographic Aspects. Iskusstvenniy intellekt, 3, 450–460. Available at: http://iai.dn.ua/public/JournalAI_2005_3/Razdel5/17_Mamedova_Dzhabrailova.pdf
29. Mamedova, M. H., Jabrailova, Z. G. (2004). Primenenie nechetkoy logiki v demograficheskom prognoze [Application of Fuzzy Logic in Population Forecasting]. Informacionnye tekhnologii, 3, 45–53.
30. Zaharets, V., Zaharets, I. (2014). Demographic Policy: Methods and Instruments, Application Experience and the Analysis of Effectiveness. Zhurnal mezhdunarodnogo prava i mezhdunarodnykh otnosheniy, 2, 71–79. Available at: http://elib.bsu.by/bitstream/123456789/102389/1/2014_2_JILIR_VSzagorets_IVzagorets.pdf
31. Eliseeva, I. I., Klupt, M. A. (Eds.) (2016). Demografiya i statistika naseleniya. Moscow, 405. Available at: https://static.my-shop.ru/product/pdf/231/2301141.pdf
32. Demographic Indicators of Azerbaijan (2017). Baku, 472. Available at: https://www.stat.gov.az/source/demoqraphy/
33. Law of Azerbaijan Republic on Protection of Health of Population. Available at: http://www.e-qanun.az/framework/4078